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An analysis of Mauritian winter rainfall

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सार – मारीसस के विभिन्न खण्डों के 12 स्टेशनों का दीर्घकालीन सरद् ऋतु के प्रलेखों का काम में लेकर दो प्रारंभिक सांख्यिकी विश्लेषण और वर्णक्रमणीय विश्लेषण किए गए हैं। जून से अगस्त तक के मुक्त महीनों के तीन चक्रवातों का इनके प्रथम अध्ययन के लिए परीक्षण किया गया है। चक्रवात ऋतु में वर्षा दूसरे लेख का विषय होगा। ऐसा देखा गया है कि शुष्क क्षेत्र वर्षा में अधिक पवितंनशीलता दर्शाते हैं। नम सर्दियां वर्ष 1885, 1909, 1926-27, 1939-40, 1951-54, 1961-62 और 1972 में रहीं। 1883-84, 1886, 1902-03, 1915-16, 1921-23, 1942-48 और 1956-57 के आस पास के वर्ष शुष्क सर्दियों वाले वर्ष रहे। तीन स्टेशन सरल मारकोव पश्चदीप्ति के प्रबल तत्व की उपस्थिति को दर्शाते हैं। वर्णक्रम विश्लेषण से पता चलता है कि आंकड़ों में वर्णक्रम शीर्ष भी होते हैं – परन्तु 95 प्रतिशत स्तर पर बहुत कम सार्थकता दर्शातें हैं। फिर भी यह आश्चर्यजनक है कि 2 वर्ष, 3 से 4 वर्ष, 10-13 वर्ष और 16 से 20 वर्ष से थोड़ी अधिक परिसीमा आवर्तिता अन्य अन्वेषणों से प्राप्त परिणामों के तुल्य पाई गई।

ABSTRACT. Long-term winter rainfall records for twelve stations from various sectors of Mauritius have been subjected to basic statistical analysis and spectral analysis. Three cyclone-free months, June-August, have been examined for this first study. Cyclone season rainfall will be the subject of a second paper. It is observed that the drier areas exhibit more variability in rainfall. The wet winters were around the years 1885, 1909, 1926-27, 1939-40, 1951-54, 1961-62 and 1972. The dry winters were around 1883-84, 1886, 1902-03, 1915-16, 1921-23, 1942-48 and 1956-57. Three stations show the presence of a rather strong element of simple Markov persistence. Spectral analysis reveals that the data do contain spectral peaks, but very few are significant at the 95% level. However, it is interesting to note that the periodicities in the ranges of slightly over 2 years, 3 to 4 years, 10 to 13 years and 16 to 20 years are comparable to the results obtained by other investigators.

1. Introduction

Mauritius is an old volcanic island about 1800 km² situated near 20.5 deg. S and 57.5 deg. E. The contours in Fig. 1 show some of the topographical features.

Mauritian economy depends largely on agriculture, and therefore on rainfall. It has sometimes been asked "Is Mauritius drying up?" Obviously, no simple answer exists to this question.

Over tropical regions year-to-year changes in temperature are of small amplitude. In middle and higher latitudes these changes are significantly greater. Since prevailing general circulation is largely influenced by such changes, year-to-year temperature variation cannot be used in the tropics as a measure of the change in the circulation features. Here, the variation of rainfall amounts can be considered as an index of changes in the circulation. An analysis of long-term rainfall records from tropical stations may, therefore, be useful in the study of climatic change.

Quite a number of stations scattered over the island possess long term rainfall records. No earlier statistical analyses of these data are traceable. This paper is probably a first statistical treatment of some of these long-term records.

Situated in the tropics, Mauritius is often visited by tropical cyclones (Padya 1976) in the southern summer season. The island relies heavily on these disturbances for its rainfall, and summer rainfall is very variable compared to winter rainfall (*see* Table 1). This is the reason why it has been decided to treat the two seasons separately.

Situated in the tropics, Mauritius if often undertaken by many investigators. Tyson *et al.* (1975) analysed time series of rainfall from a large number of south African stations. They found evidence of oscillations in some areas. Jagannathan and Parthasarathy (1975) studied Indian rainfall and showed the lack of association between the well-known quasi-biennial oscillation (QBO) and the so-called 11 - year

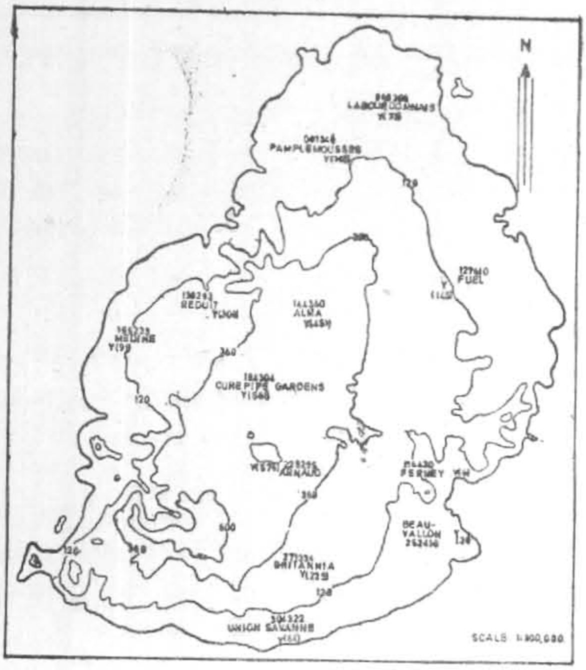

Fig. 1. Station location, height a. m. s. l. (m) (in brackets) and contours (m)

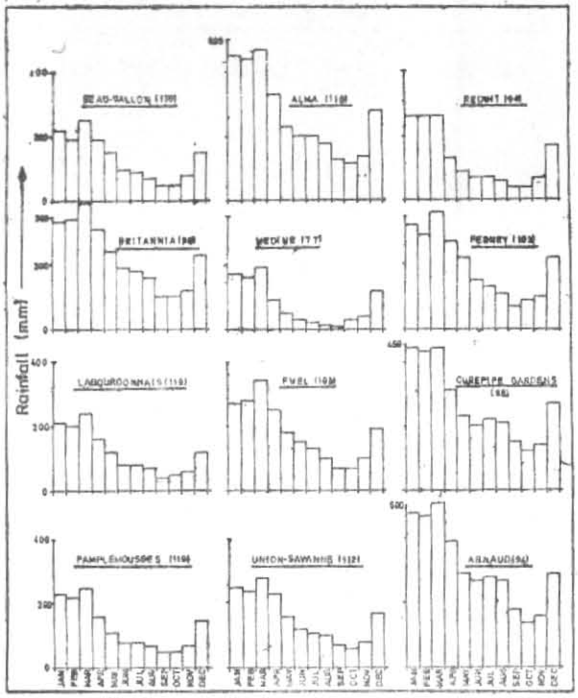

Fig. 2. Monthly long term mean rainfall (mm) and number of years of data (in brackets)

solar cycle. Kousky and Chu (1978) observed spectral peaks in the period ranges of 2-3 years, 3-5 years and 10-20 years.

Fruitful theoretical studies of climatic fluctuations are not expected at least in the near future (Mitchell *et al.* 1966). Undertaking suitable statistical analyses of time series may prove to be useful in the sense that, though the fluctuations are unexplainable on a physical basis, past history may give some indication about the future.

In an attempt to better view the variability of rainfall over Mauritius and to learn about climatic change, the intention here is to analyse the long term winter rainfall records from various parts of the island. It is hoped that studies of the variability of this basic climatic parameter in this part of the world will contribute to the understanding of the large scale behaviour of the atmosphere.

2. Data

Twelve stations with relatively long ($\sim$ 100 years) rainfall records have been selected — 2 from the northern plains (Pamplemousses and Labourdonnais) 4 from the southern/southeastern parts (Britannia, Union Savanne, Beau Vallon and Ferney), 1 from the east (Flacq United Estates Limited, FUEL), 4 from the Central Plateau (Reduit, Alma, Curepipe Gardens and Arnaud) and 1 from the west (Medine). Fig. 1 shows the location of the stations selected, their identification numbers, and their heights in metres (m) above mean sea level (amsl).

The monthly totals of rainfall for these stations were available from the Mauritius Meteorological Department. The only missing value was for the year 1920 for Reduit. The mean value has been used at the missing point. Table 1 and Fig. 2 have been presented for reference purposes. Winter in this paper has been defined as the months of June, July and August (JJA).

Table 2 lists the data periods and some of the basic statistics for winter. The percent of the seasonal (JJA) mean to the long-term (grand) mean are graphed in Fig. 3 along with binomially smoothed (5 point curves).

Homogeneity tests on the data have not been attempted in this study in view of the fact that very few stations are selected and, moreover, though Mauritius is a very small island, it can be categorized into various climatic regimes due to the mountainous topography.

Up to now, no real reference climatological stations, or, as is sometimes called, "*benchmark*" stations, have been designated. Furthermore, the record lengths differ. Since over 200 rainfall stations are presently operating, a study is being planned in order to establish reference climatological stations.

TABLE 1

Stations	Data/ Period	Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Pamplemousses	1862 to 1980 (119)	Mean(mm)	231	220	248	163	116	83	81	75	50	49	66	145	1527
		S.D. (mm)	160	146	159	101	97	53	41	41	29	36	64	138	364
		C.O.V.(%)	69	66	64	62	84	64	51	55	58	73	97	95	24
Labourdonnais	1862 to 1980 (119)	Mean (mm)	208	204	237	158	119	82	79	66	43	44	58	123	1422
		S.D. (mm)	145	152	153	109	103	57	45	45	28	37	64	123	374
		C.O.V. (%)	69	74	65	69	86	70	57	68	65	83	109	100	26
Britannia	1886 to 1980 (95)	Mean(mm)	334	336	388	313	239	193	175	155	105	100	125	234	2697
		S.D.(mm)	201	209	205	165	147	125	76	82	58	74	119	176	577
		C.O.V(%)	60	62	53	53	61	65	44	53	55	74	96	75	21
Union Savanne	1869 to 1980 (112)	Mean(mm)	254	242	275	231	158	120	114	101	68	63	83	170	1879
		S.D.(mm)	162	143	181	160	109	70	59	65	45	44	85	134	453
		C.O.V.(%)	64	59	66	69	69	58	51	64	66	70	102	79	24
Beau-Vallon	1865 to 1980 (116)	Mean(mm)	226	195	254	192	154	103	91	74	50	53	77	159	1631
		S.D.(mm)	153	119	161	120	107	60	55	54	35	51	84	141	417
		C.O.V.(%)	68	61	63	62	69	58	60	72	69	96	108	89	26
FUEL	1878 to 1980 (103)	Mean(mm)	269	278	338	248	183	145	129	100	74	65	96	192	2116
		S.D.(mm)	169	156	209	154	117	110	67	58	48	43	79	235	569
		C.O.V.(%)	63	56	62	62	64	76	52	58	64	67	83	122	27
Medine	1904 to 1980 (77)	Mean(mm)	166	161	193	89	48	31	19	16	12	27	41	124	927
		S.D.(mm)	134	99	239	72	50	37	26	37	19	34	26	126	369
		C.O.V.(%)	81	62	124	81	104	120	133	228	154	129	113	101	40
Alma	1871 to 1980 (110)	Mean(mm)	446	442	465	326	231	200	204	181	126	115	136	280	3159
		S.D.(mm)	237	226	274	200	159	98	81	84	60	68	93	240	652
		C.O.V.(%)	53	51	59	61	69	49	40	46	48	59	69	86	21
Arnaud	1887 to 1980 (94)	Mean(mm)	477	466	314	392	291	270	283	267	182	142	159	287	3730
		S.D.(mm)	253	221	298	208	165	125	106	118	80	84	121	188	820
		C.O.V.(%)	53	47	58	53	57	46	37	44	44	59	76	65	22
Ferney	1878 to 1980 (103)	Mean(mm)	322	286	363	266	222	150	129	111	71	87	101	216	2323
		S.D.(mm)	218	179	194	162	155	92	75	77	44	77	90	191	539
		C.O.V.(%)	68	63	53	61	70	62	58	70	61	88	89	88	23
Reduit	1887 to 1980 (94)	Mean(mm)	255	259	257	134	87	70	68	64	44	44	66	170	1519
		S.D.(mm)	177	150	175	96	69	46	31	36	25	31	60	199	350
		C.O.V.(%)	69	58	68	71	79	65	46	57	58	70	92	117	23
Curepipe Gardens	1883 to 1980 (98)	Mean(mm)	444	429	443	314	232	205	217	211	149	123	143	266	3177
		S.D.(mm)	249	212	235	180	138	98	79	91	63	72	101	209	617
		C.O.V.(%)	56	49	53	57	59	48	36	43	42	59	71	78	19

Mean (mm), Standard Deviation (S.D., mm) and Coefficient of Variation (C.O.V., %)

TABLE 2

Winter (JJA) rainfall basic statistics

Station	Station number	Altitude amsl (m)	Period of record	Grand seasonal (JJA) mean (mm)	Standard deviation σ (mm)	Coefficient of variation 100σ/m (%)	Highest (% of m)	Corresponding year	Lowest (% of m)	Corresponding year	Mean deviation |a| (mm)	Cornu criterion |a|/σ
Pamplemousses	061346	79	1862-1980 (119)	239	86	36	229	1972	45	1948	68	0.79
Labourdonnais	040365	73	1862-1980 (119)	226	91	40	255	1972	34	1884	71	0.78
Britannia	271334	229	1886-1980 (95)	523	192	37	281	1909	47	1941	135	0.70
Beau Vallon	252416	21	1865-1980 (116)	269	103	38	267	1909	38	1922	76	0.74
Union Savanne	304322	64	1869-1980 (112)	336	118	35	240	1909	38	1921	89	0.75
FUEL	127410	146	1878-1980 (103)	373	156	42	307	1962	43	1942	110	0.71
Medine	155233	91	1904-1980 (77)	67	61	91	492	1909	6	1922	41	0.67
Alma	144340	451	1871-1980 (110)	586	171	29	244	1953	48	1915	128	0.75
Arnaud	228295	576	1887-1980 (94)	819	228	28	209	1926	44	1957	173	0.76
Curepipe Gardens	194304	561	1883-1980 (98)	633	167	26	179	1961	46	1920	129	0.77
Ferney	216420	6	1878-1980 (103)	390	145	37	238	1909	30	1936	111	0.77
Reduit	139293	309	1887-1980 (94)	203	71	35	220	1909	37	1893	55	0.77

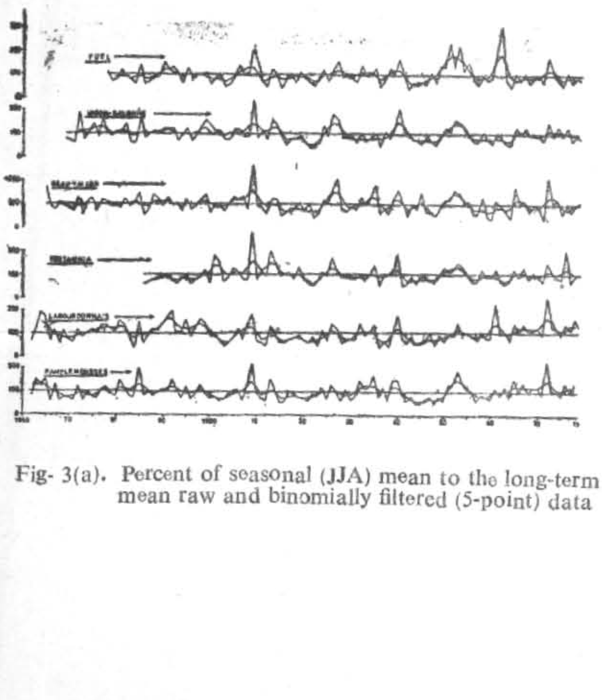

Fig. 3(a). Percent of seasonal (JJA) mean to the long-term mean raw and binomially filtered (5-point) data

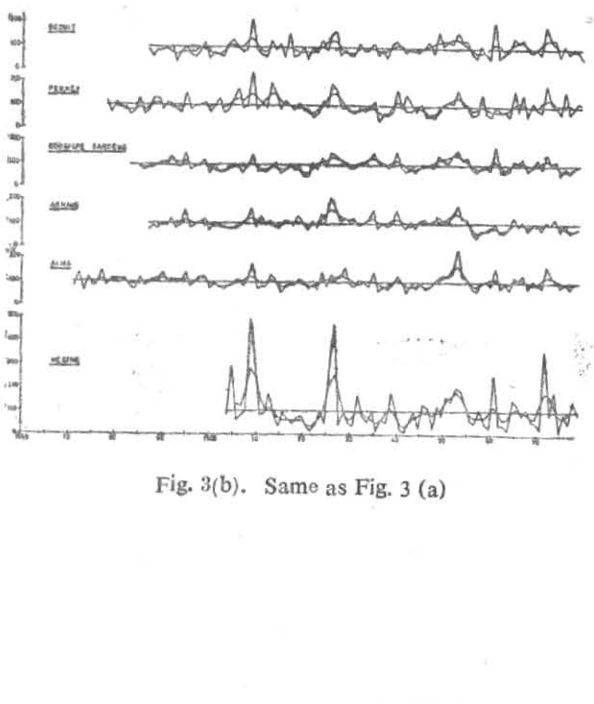

Fig. 3(b). Same as Fig. 3 (a)

3. Results and discussion

3.1. *Basic statistics*

Before embarking into complicated analyses, it is always important to look at some of the basic statistical properties of the data.

Tables 1 and 2 list the basic statistical parameters derived from the raw data sets. For reference and comparison purposes, in Table 1 are given the mean rainfall (mm), standard deviation (mm), and the percent coefficient of variation *i.e;* 100 times the ratio of the standard deviation to the mean, for all the stations month by month. Table 2 shows some of the parameters for the winter season (JJA). It is deduced that the drier areas exhibit more variability in rainfall. However, an approximate value for the standard deviation, may be estimated from Fig. 4 when the mean is known.

Most regions experienced wet winters around the following years: 1885, 1909, 1926-27, 1939-40, 1951-54, 1961-62 and 1972. The dry winters were around 1883-84, 1886, 1902-03, 1915-16, 1921-23, 1942-48 and 1956-57 (*see* also Fig. 3).

Table 2 also includes the ratio of the mean deviation to the standard deviation known as the Cornu criterion (Brooks and Carruthers 1953) here denoted by α. This parameter gives an idea of the normality of the distributions. For example, for a set of 100 observations to be normally distributed, α would be expected to lie approximately between 0.76 and 0.83 (95 per cent limits). It is seen that most of the obseravtions are roughly normally distributed. It should, however, be borne in mind that satisfaction of the Cornu criterion does not guarantee normality of a distribution.

The frequency distributions were set and the coefficients of skewness and kurtosis computed (not presented). All the distributions were observed to be slightly positively skewed (mean> mode). The plots of cumulative frequencies on normal probability paper indicated that the distributions for Medine, FUEL and Britannia are notably different from normal. An interesting observation is that, for all the stations, the mode is at about the 85 per cent point. This means that, for a particular location, the most frequent winter rainfall amount is about 85 per cent of the grand seasonal mean for that station.

3.2. *Trend*

The Mann-Kendall rank statistic (Mitchell *et al.* 1966) has been widely used in the literature as a powerful test when the most likely alternative to randomness in a climatological series is some form of trend, linear or non-linear. This test is robust, that is, departure from a normal (Gaussian) frequency distribution need not be taken in to account (Mitchell *et al.* 1966). The statistic τ is given by the equation:

$$\tau = \frac{4 \sum_{i=1}^{N} n_i}{N(N-1)} - 1$$

where n_i is the number of values greater than the i^{th} value in the series subsequent to its position in the time series. For $N \geqslant 10$, τ is closely normally distributed. The test statistic

$$(\tau)_t = t_g \sqrt{\frac{4N+10}{9N(N-1)}}$$

where t_g is the desired probability level of the normal distribution for two-tailed test.

The Mann-Kendall rank statistics, τ, as well as the corresponding upper and lower limits of the 95 per cent level test statistic, $(\tau)_t$, are tabulated in columns 5, 6 and 7 of Table 3. It is clearly seen that, for the whole period of data dealt with here, only Reduit shows a value of τ indicative of trend. But trend effects cannot be substantiated in the data analysed for all the other stations.

3.3. *Serial correlation*

Lag-one serial correlation (r_1) has been computed using the following formula :

$$r_1 = \frac{N^2/(N-1) \sum_{i=1}^{N-1} x_i x_{(i+1)} - (\sum_{i=1}^{N} x_i)^2}{N \sum_{i=1}^{N} x_i^2 - (\sum_{i=1}^{N} x_i)^2}$$

In testing the statistical significance of r_1 for the null hypothesis of randomness, the test statistic used is :

$$(r_1)_t = -1 \pm t_g \sqrt{N-2} / (N-1)$$

where, again, t_g is the value of the standard deviate in the normal distribution corresponding to the desired significance point of r_1 (Mitchell *et al.* 1966; Sneyers 1975). Wherever r_1 is positive, the one-tailed 95 per cent probability point of t_g is used, and where r_1 is negative, the two-tailed value is used. It should be noted that negative values of r_1 are indicative of marked high-frequency oscillations.

The lag-one serial (r_1) correlations for all the stations are given in Table 3. It is observed that the r_1 correlations for Britannia, Beau Vallon and Reduit are negative (high frequency oscillations) while the others show positive correlations. Performing the tests to assess the significance of the correlations revealed that the values for Labourdonnais, FUEL, and Arnaud are significantly different from zero at the 95 per cent level. This form of non-randomness was investigated further by comparing the r_1^2 and r_1^3 values for these

TABLE 3

Lag-one serial, correlations, r_1, test statistics $(r_1)t$, and Mann-Kendall statistics

Station	Lag-one serial correlation r_1	$(r_1)_t$ 95% 1-tailed	$(r_1)_t$ 95% 2-tailed	Mann-Kendall $(\tau)_t$ τ 95% 1-tailed	Statistics $(\tau)_t$ 95% 2-tailed
Pamplemousses	+ 0.038	+ 0.142 — 0.159	+ 0.171 — 0.188	+ 0.053 ± 0.102	± 0.122
Labourdonnais	+ 0.169*	+ 0.142 — 0.159	+ 0.171 — 0.188	— 0.019 ± 0.102	± 0.122
Britannia	— 0.014	+ 0.158 — 0.179	+ 0.190 — 0.212	+ 0.061 ± 0.115	± 0.137
Beau Vallon	— 0.035	+ 0.144 — 0.161	+ 0.173 — 0.191	— 0.044 ± 0.103	± 0.123
Union Savanne	+ 0.052	+ 0.146 — 0.164	+ 0.176 — 0.194	— 0.069 ± 0.105	± 0.125
FUEL	+ 0.174*	+ 0.152 — 0.172	+ 0.183 — 0.203	+ 0.023 ± 0.110	± 0.131
Medine	+ 0.057	+ 0.174 — 0.201	+ 0.210 — 0.237	— 0.036 ± 0.128	± 0.152
Alma	+ 0.010	+ 0.148 — 0.166	+ 0.178 — 0.196	— 0.028 ± 0.106	± 0.127
Arnaud	+ 0.204*	+ 0.159 — 0.180	+ 0.191 — 0.213	— 0.053 ± 0.115	± 0.137
Curepipe Gardens	+ 0.134	+ 0.156 — 0.176	+ 0.188 — 0.208	+ 0.037 ± 0.113	± 0.134
Ferney	+ 0.007	+ 0.152 — 0.172	+ 0.183 — 0.203	— 0.005 ± 0.110	± 0.131
Reduit	— 0.011	+ 0.159 — 0.180	+ 0.191 — 0.213	+ 0.148* ± 0.115	± 0.137

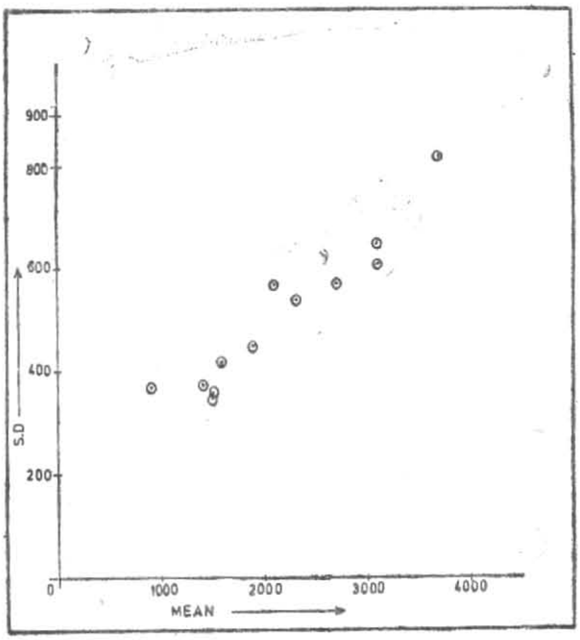

Fig. 4. Yearly mean *versus* standard deviation

stations to r_2 (lag-two) and r_3 (lag-three) values respectively. This showed the absence of simple linear Markov-type persistence (*red noise*).

3.4. *Spectral analysis*

(*a*) *Method*

The procedure used here is along the lines suggested by Jenkins and Watts (1968). For a series of N observations, x_i, $i=1, 2, .., N$, the smoothed spectral density estimates, $\bar{R}_{xx}(f)$ at frequency f and for unit data spacing (one year in this case) are given by the formula :

$$\bar{R}_{xx}(f) = 2\left\{1+2\sum_{k=1}^{N-1} M_{xx}(k)\cos\frac{\pi f k}{F}\right\},$$

$$f = 0, 1, 2.....F;\quad F=2M$$

where,

$$R_{xx}(k) = \frac{c_{xx}(k)}{c_{xx}(0)},$$

the autocorrelation function,

$$k = 0, 1, 2, \ldots, M+1;\quad \bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$$

$W(k)$ is the lag window with truncation points M, defined at discrete points k. In this study, the Tukey window has been used, so,

$$W(k) = \begin{cases} \frac{1}{2}(1+\cos(k/M), & k \leqslant M \\ 0 & , k > M \end{cases}$$

The number of frequency points, F, was chosen such that $F=2M$ in order to obtain a detailed plot of the spectral. The bandwidth, $B = 4/(3M)$ with the Tukey window, and the corresponding number of degrees of freedom, $D = 8N/(3M)$. The steps generally followed in the computation of the spectral estimates are summarized in Appendix A along with a note on the procedure (Appendix B).

(*b*) *Statistical significance tests for spectral peaks*

The significance of spectral power estimates may be determined by several methods. For example, Mitchell *et al.* (1966) suggest that, when r_1 differs from zero by a statistically significant amount, and, moreover, $r_2 \approx r_1^2$, $r_3 \approx r_1^3$, then the appropriate null hypothesis to be assumed is that the series contains Markov "*red noise*". In this study, however, it is observed that this criterion is not satisfied and a simple Markov process cannot be assumed.

The spectral power density distributions were tested against the "*white noise*" null hypothesis, that is, by assuming the generating process is purely random. The term "*white noise*" has long been stablished by analogy with the optical spectrum of white light which has all its optical frequencies present with approximately the same intensity. In plots of the spectral densities, *white noise* is represented by a horizontal straight line : equal power is allocated to all frequencies. With a maximum lag of 20, the *white noise* is estimated to be at the 0.025 level.

The confidence limits depend on the number of degrees of freedom, D, that is, on the length of record (N), on the maximum lag used (M), and on the particular window employed. For example, for $N=119$, $M=20$, and employing the Tukey window, the number of degrees of freedom$=15.87$ and the corresponding 95 per cent upper confidence limit is approximately 0.041. This result is obtained by multiplying the *white noise* value (0.025) by the chi-square divided by degrees of freedom, χ^2/D. The χ^2 values are given in Fisher and Yates (1963).

In the case of Labourdonnais, FUEL and Arnaud, the lag-one correlations were found to be significantly different from zero. Though they are not truly suggestive of Markov "*red noise*", their spectra are tested against a tentative "*red noise*" null continuum as suggested by Mitchell *et al.* (1966). This continuum was designed by using the following approximate formula :

$$S(f) = \frac{1}{M+1}\left(\frac{1-r_1^2}{1+r_1^2-2r_1\cos(\pi f/M)}\right)$$

$$f=0, 1, 2, \ldots, M,$$

$$M=\text{Maximum lag}$$

(*c*) *Results*

Spectral analysis of the rainfall data reveals some interesting features. Though many of the spectral peaks are not statistically significant at the 95 per cent level obtained from the χ^2 divided by degrees of freedom (χ^2/D) distribution, the fact that most of the curves show similar patterns is encouraging. Moreover, the spectral density estimates show peaks in regions of wave lengths corresponding to those in other studies.

Before proceeding with the comments on spectral results, it should be mentioned that the spectral peaks observed here correspond to wavelengths that were unsuspected before the analysis. As pointed out by Madden and Jullian (1971), and quoted by many investigators, when the detection of a spectral feature is *a posteriori* (that is, after the fact), the usual application of the classical chi-square sampling limits should not be used to establish confidence levels. One simple method of dealing with this problem is to raise the *a priori* χ^2/D significance level to a point where it is unlikely that any estimate exceeds that limit (Mitchell *et al.* 1966).

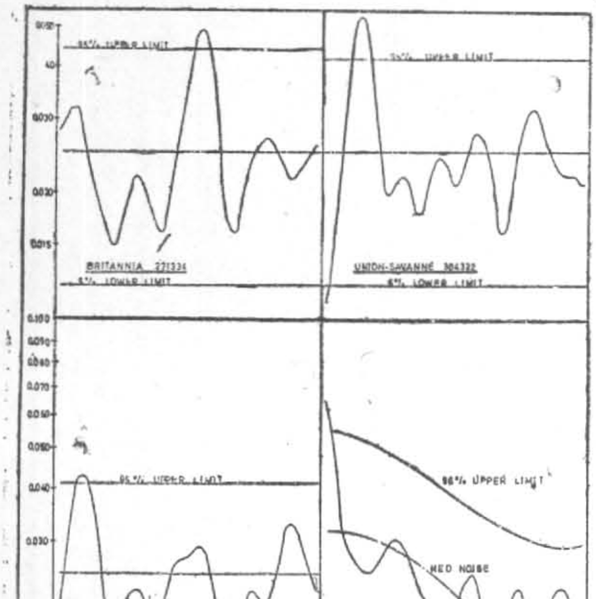

Fig. 5 (a). Spectral estimate *vs* period (years)

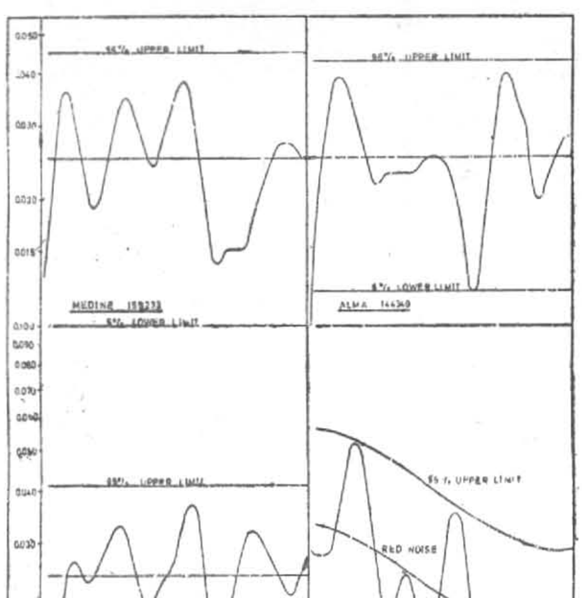

Fig. 5 (b). Spectral estmate *vs* period (years)

Smoothed spectral density profiles for the individual stations are displayed in Fig. 5. For a better view of the details in the spectra, the density estimates are presented on a semi-logarithmic frame.

The frequency scale is linear since the bandwidth is independent of frequency. The *white-noise* or *red-noise* spectra and 95 per cent lower and upper limits are superimposed.

The tentative *red noise* spectra seem to fit those of Labourdonnais, Arnaud and FUEL; that is, a rather strong element of simple Markov persistence may be assumed in these data. In spite of this, the peaks in the various regions deem comments.

Labourdonnais, Arnaud and, to a lesser extent, Reduit show remarkably high spectral power at the low frequency end, thus indicating that the series contain fluctuations corresponding to periods of the order of the record lengths. In a previous section it has already been recognized that trend effects cannot be substantiated in the data, except probably for Reduit. The spectrum of Reduit is distorted and quite different from the others. It contains high power at both extremes of the scales of fluctuation dealt with here. Because of lack of resolution, these wave bands will not be discussed on the basis of spectral analysis. Employing 5 normalized symmetrical weights, the raw data series were binomially filtered (*see* Appendix C). The smoothed series in Fig. 3 efficiently filter out the details about the low frequency variations. A slight upward trend is visible in the smoothed curve for Reduit up to 1974 (Fig. 3). Labourdonnais also shows a slight upward trend from about 1936 to 1980, while a slight downward trend is visible in the case of Arnaud from about 1926 to 1980.

The spectra of Pamplemousses and Curepipe Gardens show the presence of peaks, significant at the 95 per cent level, in the region corresponding to waveperiods in the range of 16 to 20 years. Peaks in this same waveband, but not significant, are also present in the spectra of Medine, Alma and Ferney.

On the other end of the spectrum, Pamplemousses, Labourdonnais, Medine, Arnaud and Ferney seem to peak in the region of a waveperiod slightly over 2 years, while the absence of such peaks at the other stations is noteworthy. This period, which may be thought of as a weak manifestation of QBO is not significant in any of the records analysed. It is interesting, however, to note that Alma, FUEL, Beau Vallon, Union Savanne, Britannia, and Curepipe Gardens, that is, those not exhibiting

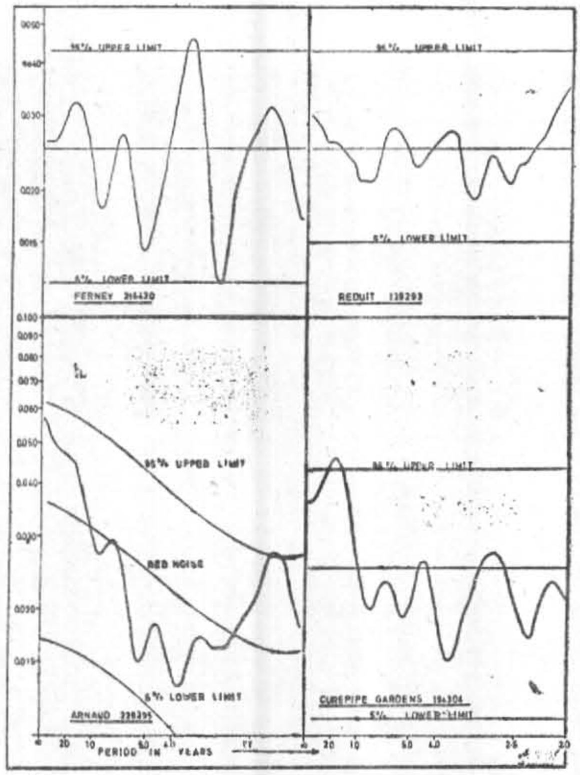

Fig. 5 (c) Spectral estimate *vs* period (years)

QBO, are all situated over the windward southern half of the island, and that most of these stations receive much of their rainfall from forced orographic lifting. Also, rainfall at these stations is much influenced by the strength of the circulation which in turn is associated with the strength and location of the subtropical high pressure cells to the south. In a study of the winter season rainfall climatology of the Dominican Republic, Garcia *et al.* (1978) observed that mountains and the interactive effects of synoptic-scale frontal zones with local terrain considerably influence the distribution of rainfall over the country. Similar interactions could be true for Mauritius also. Other rainfall producing systems are the waves in the lower tropospheric easterlies or in the upper westerlies and the interaction of disturbed trades with local topography. It is probable that the intensity and frequency of such systems are themselves influenced by the quasi-biennial pulse in such a complex mode that their effects may either be damped or increased. It is agreed with Jill Williams (1978) that no conclusions could be drawn about the quasi-biennial the spectrum for FUEL with white noise. This oscillation as that frequency is near the Nuquist (folding) frequency. Because of the limited memory of the existing calculator, the analysis of monthly data could not be executed.

The peaks corresponding to 3-4 years for Britannia and Ferney are significant at the 95 per cent level. Most of the other stations also show a tendency to peak about this period except for Arnaud and Curepipe Gardens where the absence of such peaks can be noted. The latter stations are located in the higher parts of the islands and they are in the wettest region. Troup (1965) indicated the existence of spectral peaks in similar wavelengths associated with the southern oscillation, although he postulated that these wavelengths were due to sampling fluctuations in random series.

Of particular interest is the presence of high power in the period range of approximately 10 to 13 years in the data of Union Savanne and FUEL. These peaks are found to be significant at the 99 per cent level, temporarily comparing the spectrum for FUEL with *white noise*. This phenomenon is most probably associated with the solar sunspot cycle. Absence of such peaks in the data for the other stations is not understood. If, however, it is true that circulation strength is significantly influenced by the solar cycle, the one may associate the 10-13 year fluctuation in rainfall at FUEL and Union Savanne with the circulation strength since these stations are so situated that the wind-flow in their vicinity is smooth compared to the other stations which are much more affected by orographic lifting. Further analysis is needed to support the conjecture.

The scales of fluctuations presented here are comparable to those observed by other investigators. Tyson *et al.* (1975) found fluctuations in the period range of 16-20 years, 10-12 years, and 3 - 4 years as well as the quasi-biennial oscillation in south Africa rainfall data. 2 - 3, 3 - 5 and 10 - 20 year fluctuations were also found by Kousky and Chu (1978) in their analysis of annual rainfall data from northeast Brazil. Similar period range were also found by Rodhe and Virji (1976) in east African rainfall records.

While, as already mentioned, the solar cycle may be responsible for the 10-13 year fluctuation, the physical interpretation of the other peaks are not obvious. The characteristic nonlinear interactions of the Sun-Earth-Ocean - Atmosphere model are liable to produce complex subharmonic fluctuations of the order of fractions of the scales of primary forcings such as solar heating or some other unknown forces (Brier 1978).

4. Conclusions

Rainfall data, of the order of 100 years for twelve stations scattered over the island of Mauritius have been analysed. Marked dry and wet periods are observed, and they coincide for most of the stations. Simple Markov persistence seems to explain a good fraction of the variance in the data for Labourdonnais, FUEL and Arnaud. The spectral results are comparable with those of studies for other areas of the world. The presence of peaks, significant at the 99 per cent level, at wavelengths of 10-13 years is thought to be associated with the solar cycle. Other less pronounced, peaks are noted in the period ranges of : slightly over 2 years, 3-4 years and 16-20 years. It seems that some feature of the southern hemispheric circulation pattern may be responsible for the control of temporal and spatial distribution of rainfall.

At present the phenomena as presented here receive little attention.

However, it is hoped that such studies and their results may some day help in the understanding of the underlying complex interactions. Moreover, they may prove to be useful in seasonal forecasting and "foreshadowing". Hence, increased understanding of the nature and mode of operation of these fluctuations may have at least some practical value.

Even though these fluctuations may, from the statistical point of view, only represent sampling fluctuations, such results must be taken into account in seasonal "foreshadowing".

Appendix A

On computation

All the computations were performed on the Hewlett Packard 9825A of the Mauritius Meteorological Service. The capacity of the machine is only 16K bytes and has cassette facility. Because of the limited memory of the equipment, the following steps were followed :

Type in and record monthly rainfall data for all the stations (each on separate files).
Load program to compute autocorrelation function (acf).
Load rainfall data for a station.
Compute acf and record on a data file (*say* number F).
Load spectral analysis program.
Load acf data from file F.

Compute

(1) Spectral density profile for selected truncation points,

(2) Number of degrees of freedom, and

(3) Bandwidth.

Appendix B

Note

The general objective in any spectral analysis is to estimate the spectral density as accurately as possible. In order to learn from the data enough about the shape of the spectrum and in order to achieve reasonable fidelity and stability, the window closing procedure, as suggested by Jenkins and Watts (1968), has been followed here. This technique involves computing the smoothed spectral estimates initially with a wide bandwidth (that is small lag values, M) and then using progressively smaller bandwidth (large M's). The smallest M is chosen by considering the plots of the autocorrelation functions and deducting at what lag-value the function damps out and becomes negligible. The important practical question is when to stop the process of narrowing the bandwith, that is, when to stop looking for finer details. No rigid rules are set to answer this question. In the interest of maintaining stability, a compromise has to be made. Employing several lag values, it was decided to settle the problem with a lag value of 20, thus achieving reasonable number of degrees of freedom and reasonable bandwidth.

Appendix C

Low-pass filtering

Recognizing the dangers of misinterpertation which may be associated with the application of the simple, equally weighted, moving average filter it was decided to use a 5-point binomial filter. In order to filter out the high frequency variations, the 5 weights, $W(k)$, were computed from the formula :

$$W\ (k) = \frac{n\ !}{k!(n-k)!}$$

The computed weights are : 0.06, 0.25, 0.38 0.38, 0.25, 0.06. This filter has an approximate frequency response, $R\ (f) = \cos 4\pi f$. For any frequency of variation, f, $R\ (f)$ measures the amplitude of variation in the series after filtering relative to that before filtering. The power transfer funcion, that is, the square to the response function, $R^2\ (f)$, relates the change of the fundamental spectrum when operated on by the filter.

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