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Variations of Rainfall and Seasonal Forecasting in Mauritius

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With 5 Figures

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Summary

A principal component analysis of rainfall records of 11 stations in Mauritius suggests that 70% of the variance is common to all stations. Rainfall during the summer rainy season, November to April, is closely related to the position of the subtropical high pressure belt over Eastern Australia during the preceding months. The Southern Oscillation has little influence on Mauritian rainfall. Seasonal forecasts are possible.

Zusammenfassung

Veränderlichkeiten und jahreszeitliche Vorhersage der Niederschlagsmengen in Mauritius

Eine Analyse der Niederschlagsaufzeichnungen von 11 Orten in Mauritius nach der Hauptkomponenten-Methode zeigt, daß 70% der Varianz der Niederschlagsmenge zu allen Meßpunkten gemeinsam sind. Die Menge des Niederschlages während der Sommer-Regensaison ist mit der Breiteposition des subtropischen Hochdruckgebietes stark verbunden. Es ist daher möglich, die jahrszeitliche Niederschlagsmenge vorauszusagen. Die "Southern Oscillation" beeinflußt den Niederschlag in Mauritius nur wenig.

1. Introduction

The island of Mauritius is in the Indian Ocean, at approximately 20°S and 57°E. Mauritius is about 60 by 40 km. An upland area, mostly between 300 and 600 m, but with peaks to 850 m, occupies the south and centre of the island. The north is low and flat (Fig. 1). For most of the year Mauritius lies within the S. E. trade winds but during the summer months tropical cyclones and depressions associated with the seasonal movement of the Inter Tropical Convergence Zone affect the island. Rainfall is seasonal with a wet season from November to April and a dry season from May to October [1]. For much of the island about 30% of annual rainfall occurs during the dry season, with about 40% in the highest areas and only 15% on the sheltered west coast (Table 1). Mean annual rainfall varies from 900 mm in this sheltered area (e. g. Medine) to over 4000 mm in the highest areas (e. g. Arnaud).

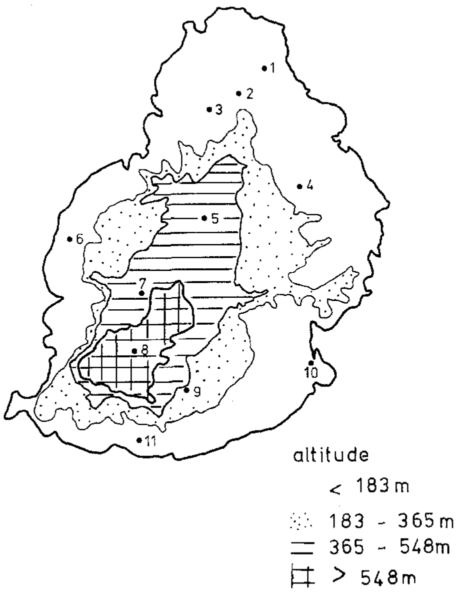

Fig. 1. Relief map of Mauritius with rainfall stations used in the analyses. Numbers refer to Table 1

Table 1. *Rainfall Stations Used in the Analysis*. Numbers refer to Fig. 1. 1 = Station Number and Name; 2 = Height, m; 3 = First year of record; 4 = Mean annual (Nov–Oct) rainfall (1904–1974), mm; 5 = Coefficient of variation Nov–Oct, %; 6 = % of annual rainfall during May to October

	1	2	3	4	5	6
1	St. Antoine	30	1874	1241	28	31
2	Labourdonnais	73	1865	1327	26	31
3	Pamplemousse	79	1862	1484	27	30
4	Union Flacq	146	1878	2193	31	33
5	Alma	451	1873	3155	22	34
6	Medine	91	1904	938	40	17
7	Curepipe	564	1883	3288	23	36
8	Arnaud	576	1887	3818	24	39
9	Brittania	232	1886	2713	22	29
10	Beau Vallon	34	1865	1635	29	32
11	Union Savanne	64	1869	1833	26	33

Station locations are shown in Fig. 1 and Table 1. The main period used in the analysis was 1904–1975 for which records were available at each station. Rainfall anomalies at each station for each month or season were calculated as the percentage departure from the 1904–1975 mean at that station. The wet season, November to April and the year, November to October, have been designated by the year containing the April.

2. Variation of Rainfall in Space

Principal component analyses were carried out on the correlation matrix of the rainfall departures, using stations as variables and years as observations. Principal component analysis provides the most economical representation of the variation in the data matrix in terms of a number of orthogonal linear combinations of stations, the principal components or eigenvectors [2, 3]. The technique has recently been applied to the study of rainfall variations [4–7].

Separate analyses were made of annual, wet and dry season anomalies. In each case the first component accounted for about 70% of the variance (Table 2). The coefficients of the first component for November to October

Table 2. *Percentage and Cumulative Percentage of Variance Extracted by Principal Component Analyses of Percentage Rainfall Anomalies for 11 Stations, 1904–1974*

Component	Nov. to Oct		Nov. to April		May to Oct.	
	%	Cum.%	%	Cum.%	%	Cum.%
1	65.8	65.8	72.3	72.3	61.4	61.4
2	9.0	74.8	7.1	79.4	9.1	70.5

shows little variation over the island (Fig. 2). Thus, about 70% of the variance is common to all stations. The second component has coefficients of opposite sign in the north and south of the island. Higher components had eigenvalues of less than one. These most probably represent noise and will not be considered further.

Stations can be grouped into homogenous areas by rotating the eigenvectors [5]. However, this is not necessary for the simple situation here since two main groups of stations can be identified from the loadings of the first two components (Fig. 3). The two groups are basically the North and South of the island with two intermediate Stations (Alma and Curepipe) on the Northern edge of the upland plateau. Similar results were obtained from the analysis of May to October anomalies except that Medine was placed

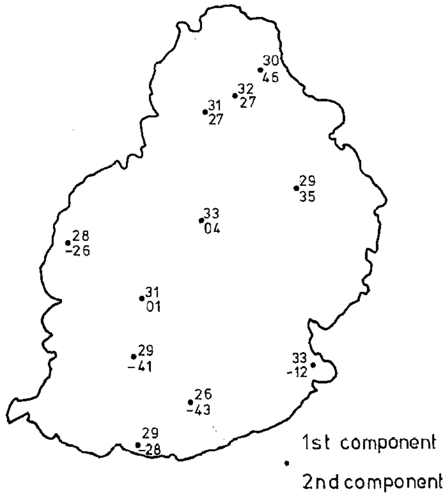

Fig. 2. Coefficients of the first and second principal components of November to April percentage rainfall anomalies, 1904 to 1974

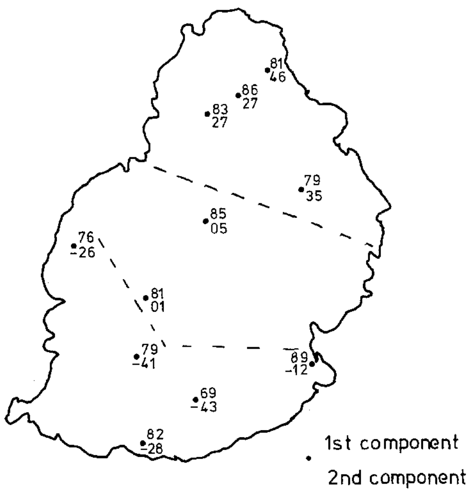

Fig. 3. Loadings of stations on the first two principal components of November to April percentage rainfall anomalies, 1904 to 1974. Dashed lines divide stations into homogenous rainfall regions

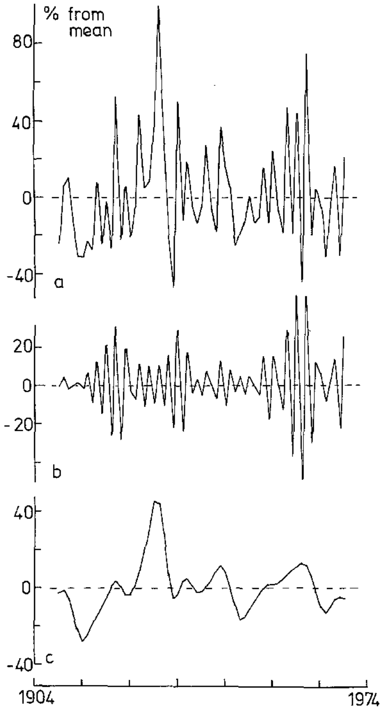

Fig. 4. a) November to April rainfall series for Mauritius calculated as the mean of percentage departures for 11 stations, 1904 to 1974. b) The series in a) treated with a high pass filter excluding all oscillations of more than 3.3 year period. c) The series in a) treated with a low pass filter excluding all oscillations of less than 5 year period

in the opposite (Northern) group. Medine is on the sheltered west coast where the dominant rainfall mechanism depends upon sea breezes [8]. Average rainfall series for the North and South of the island where derived by taking the mean of the rainfall anomalies. A similar series for the 11 stations was also derived (for example Fig. 4 a). This series is virtually identical to the time series of the first eigenvector as the coefficients of the first principal component do not vary much over the island.

3. Variations of Rainfall in Time

Spectral analysis of the average rainfall series, using the method of Blackman and Tukey [9], showed slight peaks in the spectra for periods of about 2 years and greater than 30 years (Table 3). These peaks were investigated

Table 3. *Spectral Analysis of Seasonal Rainfall Anomalies*

% of variance in band centred on frequency shown (* $P < 0.05$, ** $P < 0.01$)

Frequency (cycles per year)	0.025	0.005	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.475
Period (years per cycle)	40	20	10	6.7	5.0	4.0	3.3	2.9	2.5	2.2	2.1
11 Station average 1904–74 (13 d.f)											
Nov–Oct	9.5	9.3	7.3	6.0	9.9	10.7	6.9	7.4	11.8	12.8	11.3*
Nov–April	7.8	8.0	6.7	6.3	9.9	9.9	6.9	7.5	11.4	13.9	13.9**
May–Oct	4.2	11.8	13.3	9.6	8.1	11.1	11.7	10.1	9.9	6.6	3.7
5 station average north 1878–1974 (19 d.f)											
Nov–Oct	9.4*	8.9	8.0	7.7	8.0	7.6	7.2	8.7	13.5	13.8	10.9*
Nov–April	7.0	7.8	8.2	8.9	8.7	7.4	6.9	7.9	12.4	14.6	13.2**
May–Oct	5.5	11.3	13.7	10.4	7.4	9.4	11.0	10.5	9.3	6.2	4.5
5 station average south 1887–1974 (17 d.f)											
Nov–Oct	11.3*	9.1	5.8	5.2	9.4	11.1	9.6	9.9	11.1	10.6	8.9
Nov–April	8.9	7.8	5.8	6.1	10.3	10.4	8.6	9.8	12.1	12.1	10.8*
May–Oct	6.9	12.1	11.2	7.0	5.9	9.8	11.5	11.9	13.3	7.9	2.9
Null hypothesis	5	10	10	10	10	10	10	10	10	10	5

using filters based on those suggested by Craddock [10]. The peak at about 2 years arises from a strong quasi-biennal oscillation evident from 1917 to 1925 and from 1956 to 1965 (Fig. 4 b). The peak at about a 30 year period does not arise from any regular periodicity (Fig. 4 c). The large peak in the early 1930's is due to 5 severe cyclones between 1925 and 1934 [11].

4. Relationships Between Rainfall and the Atmospheric Circulation

An earlier study of rainfall in Fiji [7], which is at a similar latitude in the Pacific Ocean, showed that Wright's Index of the Southern Oscillation (SOI) [12] was strongly associated with variations in rainfall. For Mauritius however, correlation coefficients between the eigenvectors of rainfall and the SOI were low (Table 4). Walker's [13] original correlations of surface pressure with his Southern Oscillation Index, reproduced in [14], were +0.8 for Fiji and −0.12 for Mauritius. The Southern Oscillation does not play an important part in the variation of rainfall in Mauritius. Its influence is apparently restricted to a weak effect on the second component in the wet season.

Pittock [15] derived values of the latitude (L) of the subtropical high pressure belt over Eastern Australia. He found statistically significant correlations between L in August, September and October (ASO), rainfall and upper air temperatures over large parts of the southern hemisphere. Correlation coefficients between 3 month mean values of L and the rainfall eigenvectors are given (Table 4). There is a strong correlation between the November to April first component and the preceding ASO value of L.

Correlation coefficients between monthly values of L and the 11 station average series are given (Table 5). Statistically significant correlations exist for each month from July to November. A quadratic regression on the ASO mean value of L provided the best fit, accounting for 75% of the variance in rainfall (Fig. 5). Nevertheless, the scatter is considerable and a more useful representation is the 2×2 contingency table given in Table 6.

During the period 1942 to 1971 there have been four major cyclones which have directly affected Mauritius. These were in 1945, 1960, 1962 and 1964 [11]. Since cyclones may give 24h rainfalls of as much as 400 mm [1] it is possible that these years may be responsible for the relationship between L and seasonal rainfall. However, a quadratic regression omitting these years different only slightly from the original regression and is statistically significant with $P < 0.001$ (Fig. 5).

It is noticeable that these four cyclones occurred after values of L which were above average, having deviations from the mean of 1.2, 1.8, 2.1 and 1.0 standard deviations respectively (Fig. 5). L is not statistically significantly related to the total number of intense tropical depressions and cyclones in

Table 4. *Correlation Coefficients Between the First 2 Eigenvectors and Three-Monthly Value of Wright's Southern Oscillation Index (SOI) 1904–1973; and the Latitude of the Subtropical High Pressure Belt (L) (from* [15]), *1941–1970*. Underlined values are simultaneous correlations. ($*P < 0.05$, $**P < 0.01$, $***P < 0.001$)

SOI	Nov. to April		May to Oct.	
	1	2	1	2
FMA	–.057	.120	.009	.194
MJJ	–.242*	.127	.032	.141
ASO	–.177	.218	.056	.196
NDJ	–.158	.213	–.053	.157
FMA	–.085	.376**	.033	.161
MJJ	–.087	.101	–.155	–.113
ASO	–.025	.027	.081	–.082
L				
FMA	–.153	.150	–.144	.100
MJJ	.344*	.152	.067	.197
ASO	.791***	.142	.115	–.001
NDJ	.072	.260	.077	.481**
FMA	–.045	.275	–.161	–.032
MJJ	–.182	–.242	–.097	–.099
ASO	–.552	–.279	.016	–.099

Table 5. *Correlation Coefficients Between Monthly Values of the Latitude of the High Pressure Belt Over Eastern Australia (L) and the Subsequent November to April Rainfall in Mauritius, 1941–1970*. ($* P < 0.05$, $** P < 0.01$, $*** P < 0.001$)

Month	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
r	0.054	0.239	0.657***	0.471**	0.438*	0.358*	–0.176

Month	r	
ASO	.798***	all years
ASO quadratic	.868***	
ASO	.695***	excluding cyclone years
ASO quadratic	.798***	

Table 6. *The Relationship Between L and Rainfall in the Form of a Contingency Table*

		November to April Rainfall Anomaly	
		< –7%	> –7%
Aug., Sept., Oct. mean value of L	< 29.5°S	4	11
	> 29.5°S	11	4

$Y^2 = 6.35, P < 0.02$

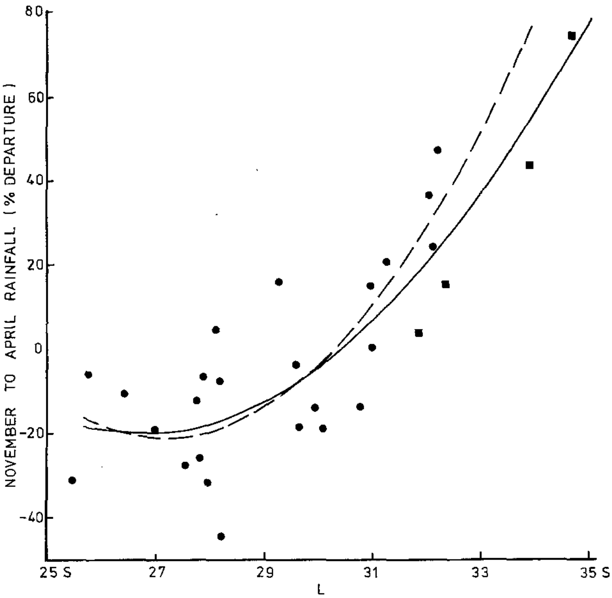

Fig. 5. Relationship between mean November to April percentage rainfall anomalies and the mean preceding August, September and October position of the subtropical high pressure belt over Eastern Australia (*L*, from [15]). ■ cyclone years, ● cyclone-free years. Quadratic regressions for all years (——) and years without cyclones (– – – –) are shown

the South West Indian Ocean between November and April. For the period 1942 to 1961, using depression numbers from Chausard and Laplace [6], $r = 0.17$, and for 1951 to 1971 using number from [11] $r = 0.08$. The position of the subtropical anticyclone in the Indian Ocean affects cyclone tracks. The southerly component of cyclone movement tends to be decreased when the anticyclone is further north or more intense [16, 17].

5. Discussion

Pittock [15] suggested that values of *L* were broadly representative of the Southern Hemisphere. He thought that sea surface temperature, which varies relatively slowly, was a major factor in determining *L*. Consequently he suggested that *L* had potential for seasonal and year to year forecasting over large areas of the globe. Annual rainfall for an area of South Africa at about 27°S was negatively related to *L* in January of the current and June of the preceding year and positively to *L* in March and February of the preceding year [18].

November to April rainfall for Mauritius is positively related to L for each month between August and November. The mean value of L for August, September and October sufficiently describes the variation of L. Most of the correlations between L and rainfall and temperature [15] were for this 3 month value of L. These three months correspond to the maximum equatorward displacement of the high pressure belt [15] and may therefore describe the extreme winter characteristics of the South Hemisphere circulation. For the Central America-Caribbean area rainfall predictions based on the preceding winter circulation appear more promising than those based on shorter lead times since the anomaly patterns in the transition season are less distinct [19, 20].

According to Pittock [15] L is determined by the mean conditions necessary for the onset of baroclinic instability and thus by the intensity of the Hadley circulation. When the latter is strong, the high pressure belt is nearer the equator. Trenberth [21] however suggested that L is large when the Hadley circulation is strong. This is in general agreement with Namias [22, 23] who suggested that a weak subtropical high was linked to an equatorward movement of the westerlies and a weak Hadley circulation. Low summer rainfall in Mauritius occurs when the island is outside the path of the low pressure troughs and depressions, that is when the subtropical anticyclone is further north than usual [1]. Recent work on drought in N. E. Brazil has shown that in drought years the S. Atlantic High has expanded towards the equator [24]. Sea surface temperatures in the S. Atlantic (0–20°S) are below average in dry years and above average in wet years. The zone of sea surface temperature that has the highest correlation with rainfall in N. E. Brazil moves eastward across the Atlantic during the months preceding the rainy season [25]. Similar variations of sea surface temperature may occur in the Indian Ocean.

Useful forecasts of summer rainfall, using L, are clearly possible. A contingency table (Table 6) can be used to indicate the character of the season to come. In addition some forecast of the probability of a cyclone is possible since more cyclones reach Mauritius when L is above normal. However, no clear physical reasons are apparent for the above relationships. Until these emerge the statistical relationships should be constantly reviewed.

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