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Rainfall Shortage and El Niño–Southern Oscillation in New Caledonia, Southwestern Pacific

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ABSTRACT

About three months after the beginning of an El Niño/Southern Oscillation (ENSO) year, a rainfall shortage develops over all of New Caledonia (21°S, 165°E) and lasts for 12 months. There is, on the average, a 22% decrease over the mean monthly rainfalls for one year. This result is based on the study of a rainfall composite and of a composite obtained from the first empirical orthogonal function (EOF) extracting more than half of the variance over 30 years of measurement at 18 stations.

1. Introduction

a. Rainfall in New Caledonia

According to ORSTOM (1981), the climate of the island is influenced by the annual variations in latitude of the subtropical anticyclonic belt in the south, and of the South Pacific Convergence Zone (SPCZ) in the north. The warmest and the wettest period of the year occurs between December and April when the SPCZ has the southernmost location. New Caledonia is then affected by tropical storms, or even tropical cyclones, which appear irregularly in number and strength and mostly influence the rainfall balance of this season. After April, the precipitation tends to decrease, reaching a minimum in September at Noumea (Table 1), when the South Pacific Convergence Zone has its northernmost location. However, a weak recovery of rainfall occurs during the southern winter. In June, for instance, the subtropical anticyclonic belt is not continuous, and between the anticyclones, storms of polar origin take place, inducing in New Caledonia west wind bursts and strong rainfalls. The irregularity in the occurrence of the storms and cyclones is mainly responsible for the strong interannual variability. However, the geographical distribution of precipitation is stable from year to year and shows a great dissymmetry between west coast and east coast (Fig. 1). This is due to the mountain pattern, to the general orientation of the island, and to the prevailing east winds.

b. Relations between ENSO phenomena and precipitation in the Southwestern Pacific

According to Philander (1983), the El Niño/Southern Oscillation (ENSO) phenomenon can be considered as the most remarkable example of interannual climatic variability on a large scale. In the Pacific Ocean, it is associated with strong rainfall fluctuations and with changes in sea surface temperature and trade wind intensity. In the rest of the world, it has been correlated with droughts in India, Australia and Brazil and with severe winters in North America. In the western Equatorial Pacific, the ENSO phenomenon is characterized by an eastward shift of the ascending branch of the Walker cell to an area located between eastern New Guinea (150°E) and 180°, while it is usually located around 130°E. This Walker circulation modification is related, west of 180°, to a change of wind regime and precipitation: There is an obvious weakening of rainfall in Indonesia, while at the same time there is a strong increase of equatorial precipitation close to the date line (Rasmusson and Carpenter, 1982). Donguy and Henin (1980) have noticed a correlation between precipitation in the western Pacific (150°E–150°W) during the austral summer and the El Niño intensities following the classification of Quinn et al. (1978). Two areas can be distinguished: the subtropical zone (10°–25° latitude) with a negative correlation and the equatorial zone with a positive correlation. Wright (1977) reached the same conclusion based on the no-lag correlation between rainfall and the Southern Oscillation Index. For New Caledonia, he obtained a −0.3 correlation coefficient for the period December–February. The goal of the present study is to try to refine for this area, using two different analyses, the relationship between the rainfall shortages and the ENSO events.

2. Methods

a. Data

Data used are the monthly precipitation recorded by Service Territorial de la Météorologie de Nouvelle

TABLE 1. Mean monthly rainfall for Noumea (1903–83): standard deviation (SD) and coefficient of variation (CV).[a]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	103	118	143	115	89	106	87	67	44	48	50	75
SD	71	92	99	84	58	75	52	42	36	42	58	65
CV	0.69	0.78	0.69	0.73	0.65	0.71	0.60	0.63	0.82	0.88	1.16	0.87

[a] CD is SD divided by the mean.

Calédonie in twenty stations distributed over the whole territory (Fig. 2). The period of record is variable according to the station (Table 2). For the calculation, we used the ratio of monthly recorded rainfall over monthly mean rainfall.

Let R_{mas} be this rainfall ratio for the month m, the year a and the station s, defined as:

$$R_{mas} = P_{mas}/(1/N * \sum_{a=1}^{N} P_{mas}),$$

where P_{mas} is the monthly precipitation and N is the number of years of observation. This ratio has been used in order

1) to eliminate the seasonal variations at each station;

2) to increase the stationarity of the variance of the rainfall time series at each station, as compared to the variance of rough monthly anomalies (Table 1);

3) to standardize the variability among the stations (coefficient of variation with a range from 0.5 to 0.8).

However, this ratio does not normalize the rainfall index distribution, which remains very asymmetric for each station. The distribution of this ratio is given in Fig. 3 for Noumea (the longest series of data). To normalize the distribution we used a cubic root transform, so $R3 = R^{1/3}$ is used for all the EOF calculations. We have tested the normality of the transformed distribution (Fig. 3) with a Kolmogorov-Smirnov test. For each station, the test indicated a good fitting of the new distribution with a normal one at a significance level better than 0.01. In other words the cube root transformation was very successful in normalizing the data.

b. Processing

The precipitation ratios ($R3$) are processed using the methods of decomposition into empirical orthogonal function (EOF) (Lorenz, 1956) under the form

$$R3(x, t) = \sum_{I=1}^{18} A_I(t)B_I(x).$$

The time functions $A(t)$ cover the 1952–83 period for which a maximum of data exists with the longest period of observation. The space functions $B(x)$, or eigenvectors, are extended over the entire New Caledonia area but only to the 18 stations whose data cover the 1952–82 period.

On the other hand, for each of the 20 stations, a composite of the rainfall ratios for the ENSO years and adjacent years was calculated for the maximum period of data available. An overall composite for New Caledonia was computed using the average of different composites; the period of record is not the same for

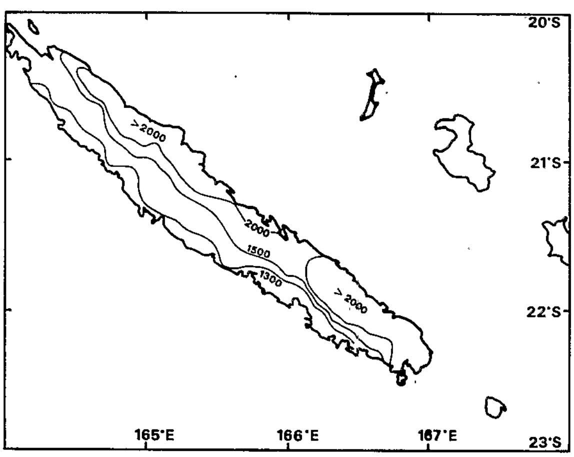

FIG. 1. Mean annual rainfall over New Caledonia (in mm).

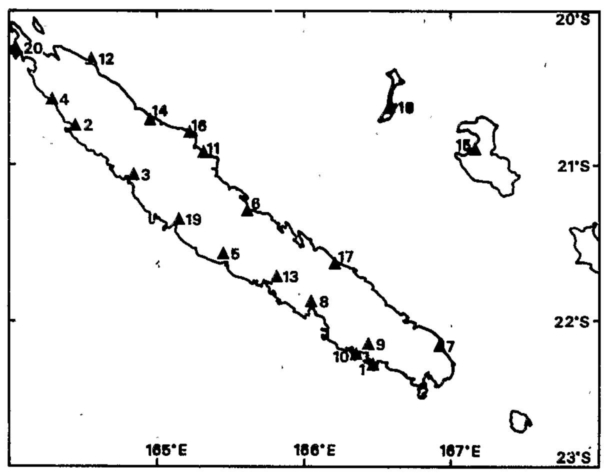

FIG. 2. Location of rainfall stations. (See Table 2.)

TABLE 2. Characteristic of rainfall stations. The monthly mean shortage (last column) is computed over a twelve-month period beginning in April of an ENSO year. Stations 11 and 12 are not included in EOF computation but in that of individual composite.

Number	Station name	Latitude (S)	Longitude (E)	First year on record	Mean yearly rainfall (mm)	Variance of $R = P/\bar{P}$ 1952–83	Monthly mean shortage (%)
1	NOUMEA	22°16	166°27	1903	1014	0.49	23
2	GOMEN	20°41	164°24	1909	1118	0.83	24
3	KONE	21°03	164°45	1921	1160	0.66	22
4	KOUMAC	20°34	164°17	1951	1018	0.85	20
5	BOURAIL	21°40	165°31	1947	1087	0.65	27
6	HOUAILOU	21°20	165°38	1951	1926	0.66	21
7	YATE	22°12	166°58	1936	2995	0.46	14
8	TONTOUTA	22°01	166°13	1951	968	0.59	26
9	PAITA	22°10	166°24	1936	1153	0.54	25
10	POINDIMIE	20°55	165°22	1964	1158		16
11	POUEBO	20°24	164°37	1956	2236		29
12	LA FOA	21°52	165°52	1951	1169	0.70	26
13	HIENGHENE	20°42	164°56	1951	2253	0.67	20
14	CHEPENEHE	20°47	167°09	1951	1626	0.64	21
15	TOUHO	20°47	165°14	1952	2574	0.55	19
16	THIO	21°36	166°14	1952	1718	0.75	31
17	FAYAOUE	20°39	166°32	1952	1216	0.68	21
18	POYA	21°20	165°08	1952	1161	0.75	32
19	POUM	20°15	164°03	1952	1301	0.76	18
20	POINTE MA	22°17	166°22	1936	877	0.60	26

each station, so we have weighted the data of each composite with the number of ENSO events observed at the station, in order to obtain a composite for the whole of New Caledonia.

The list of El Niño events involved in the calculations is obtained from Quinn et al. (1978) (Table 3). For the period prior to 1950, only strong events (index more than 2) are considered.

3. Results and discussion

a. EOF 1

The first eigenvector extracts 64% of the total variance. It is always positive (between 0.2 and 0.3), which indicates that New Caledonia is a homogeneous entity with respect to large-scale rainfall fluctuations, but there is also strong small-scale variability. Its geographical distribution (Fig. 4a) is similar to that of the annual mean rainfall (Fig. 1) pointing out the same asymmetry between east coast and west coast and also the peculiarity of the south of the island; the spatial vector distribution is roughly in reverse to that of the annual rainfall. Therefore, the first time function better represents the relative rainfall variability for the stations located on the west coast than that of the east coast, an area of heavier mean precipitation.

The variations for this first EOF (Fig. 4b) represent the interannual rainfall variations over the whole of New Caledonia. They point out, after filtration of the important short-term variability, long periods of positive and negative values that correspond to periods of rainfall excess or periods of rain shortage. For instance, the year 1967 was the rainiest at every station during 1952–82. On the other hand, during the 1977–81 pe-

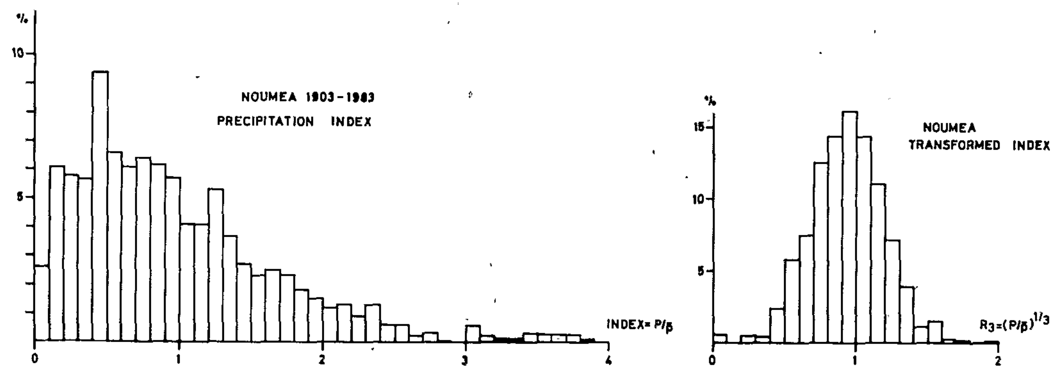

FIG. 3. Distribution of monthly rainfall ratios for Noumea station; 1903–83.

TABLE 3. List of El Niño years used in this study (from Quinn et al., 1978).

1905	1941
1911	1951
1914	1953
1918	1957
1923	1965
1925	1969
1930	1972
1932	1976
	1982

riod, New Caledonia received less rainfall than average. Moreover, EOF 1 shows that, if each ENSO phenomenon (Table 3) was associated with a rainfall shortage, the opposite is not true since rainfall shortages can occur without ENSO phenomenon as happened between 1979 and 1981. This means that only a small but significant part of the total variability can be explained by the Southern Oscillation fluctuations. Actually, the cross-correlation between SOI monthly anomalies and rainfall EOF 1 indicates a flat maximum less than 0.3 in the 0–6 month lag range.

In order to specify the relation between the precipitation and the ENSO phenomenon, the mean value of EOF 1 was computed for each month of 7 ENSO and adjacent years. The composite of EOF 1 obtained from this calculation for a complete ENSO period is shown in Fig. 5. It shows a rainfall shortage centered about one year after the starting of the event; this shortage is well marked as early as April of the ENSO year and then occurs irregularly during 12 months in a row. During the southern winter, the shortage weakens as New Caledonia is exposed to the influence of the temperate zones which, during ENSO, are not so much involved in the climatic changes occurring in the intertropical Pacific zone. Notice however, that this recovery cannot be attributed to unseasonal tropical cyclone activity, which was not observed during the entire period under investigation. After October, the shortage is again obvious until April of the next year.

b. EOF 2

The second eigenvector extracts only 8% of the total variance and is not shown. A simple test of significance (North et al., 1982) applied to eigenvalue shows that this function probably does not represent a real physical phenomenon.

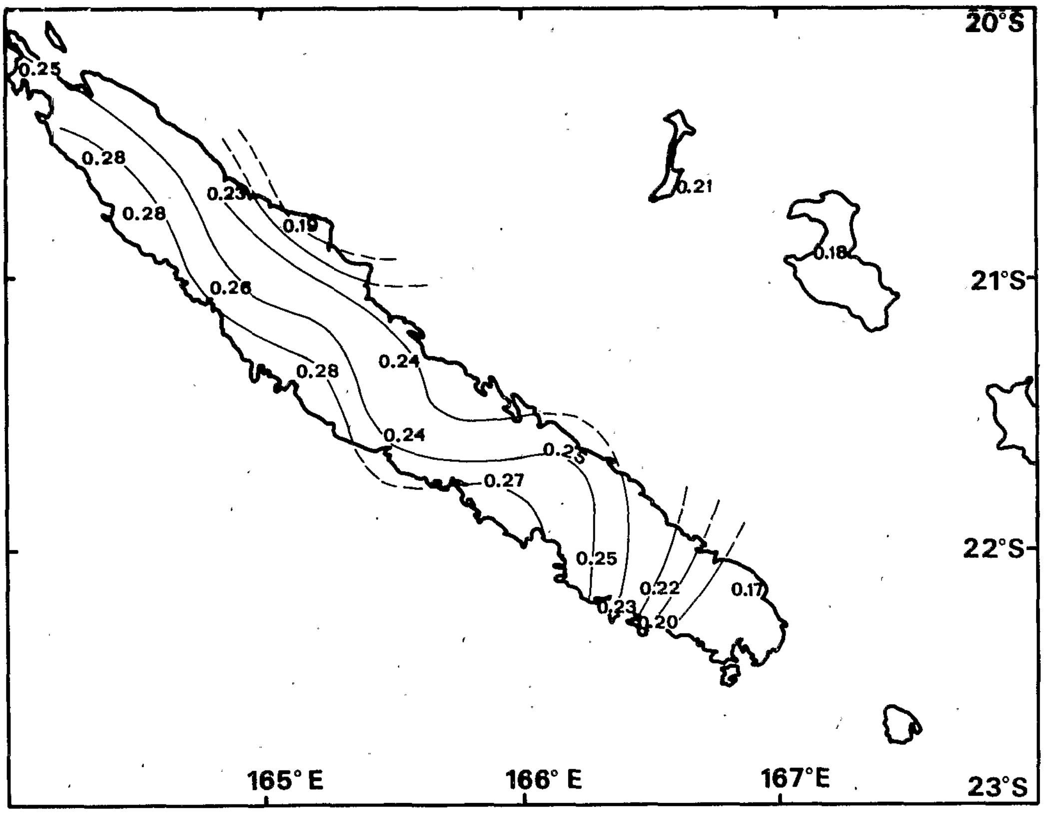

FIG. 4a. Distribution of the first eigenvector expressing 64% of the variance of monthly rainfall ratio (contour interval 0.20).

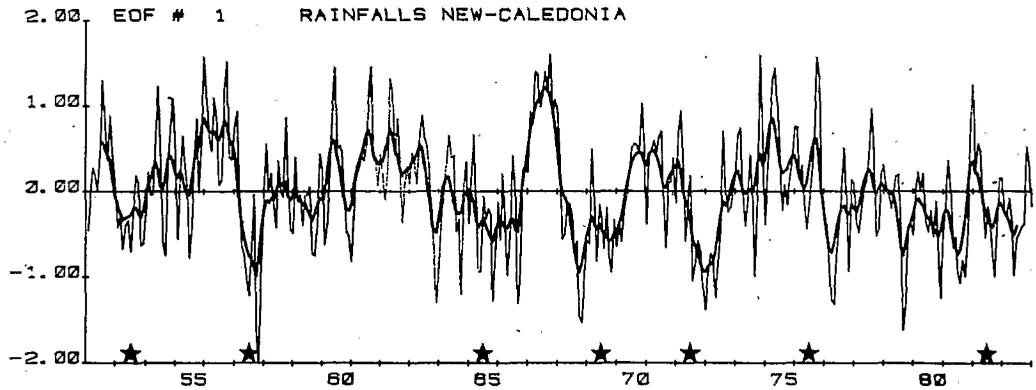

FIG. 4b. Time function associated with the first eigenvector (1952–83) (thin line: monthly value; thick line: monthly values filtered by a twelve-month Hannings filter; the stars indicate El Niño years).

c. Composite of the rainfall ratios

Obtained over the entire New Caledonia area during ENSO periods (Table 4), the composite of the rainfall ratio is similar to that obtained from the EOF 1 (Fig. 5). It points out that the rainfall shortage occurring from April of the ENSO year to April of the following year represents a decrease of 10–35% of the monthly rainfalls; the monthly mean shortage is 22% over the 12-month period. In order to test the statistical significance of this result obtained with observations that are not normally distributed, we used a nonparametric method: the Wilcoxon two-sample test. For each station we calculated mean R over twelve months from April to March and made two samples, one for the ENSO period (beginning with April of the years selected using Table 3) and one for the non-ENSO period. The Wilcoxon test for two-sample observations not paired (Sokal and Rohlf, 1969) shows that the two samples are significantly different at a probability better than 95% for all stations except for three of them, which are significantly different only at 90% level. These stations are the southeast (YATE 7), the northeast (POUM 19) and the shortest series (POINDIMIE 10). However, the spatial distribution (Fig. 6) is slightly different from that of EOF 1; the orientation of isolines is less longitudinal while the shortage maximum is clearly concentrated in the center of the island, where appears a belt of shortage as high as 30%. The physical interpretation may be based on the important part of the orography in the rainfall distribution since the topography is mostly dominated by the presence of two mountain masses, one in the south and one in the north of the island. It is also possible that ENSO phenomenon could be associated with changes in wind directions in the Southwestern Pacific and that consequently some areas would be more affected than others by the rainfall shortage. However, as the Loyalty islands, which are very flat, have exactly the same monthly mean shortage of 21% during ENSO year, this percentage probably also represents the mean rainfall shortage over the oceanic area during the same period.

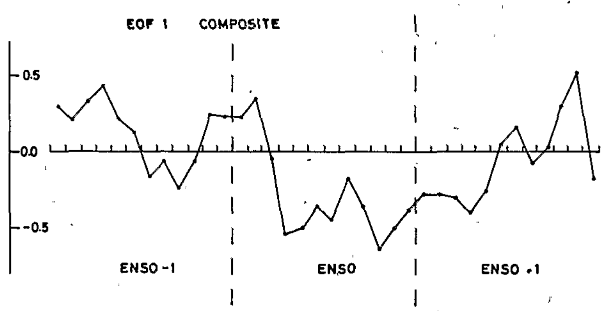

FIG. 5. Composite of EOF 1 for eight ENSO events (1952–83) filtered on three months, using ¼, ½, ¼ weights.

4. Conclusions

This first study regarding droughts associated with ENSO over New Caledonia demonstrates the following.

1) The typical duration of the rain shortage is about one year, beginning in April during an El Niño year, with a double peak of drought corresponding to the two main rainy seasons covered by this time period.

2) The long-term rainfall variability may be expressed by no more than one empirical function over New Caledonia, but the island has sufficient contrast that the pattern of the effects of the droughts induced by ENSO points out interesting geographic variations. However, the possibility to forecast such events is more complicated. The poor correlation with the Southern Oscillation index shows that only a small part of the rainfall variance is predictable through ENSO, if any. For instance, it is obvious from EOF 1 that there is a discrepancy between the 1982 El Niño intensity and the associated drought in New Caledonia. The level of

TABLE 4. Composite of the rainfall ratio (in %) averaged for the whole New Caledonia (weighted mean of 18 stations).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ENSO − 1	107	106	114	133	110	123	87	115	99	96	118	135
ENSO	102	137	97	56	62	94	69	92	97	74	60	77
ENSO + 1	78	70	74	72	81	99	127	88	94	129	120	90

significance on the monthly shortage, as noticed, has voluntarily been omitted. Though the one year shortage is obviously significant, the monthly variability in a drought period is strong, and in order to interpret the shortage in probabilistic terms one would need to adjust the rainfall distribution or to transform this distribution to percentile ranks; in particular the significance of the rainfall excess preceding an ENSO event should be checked.

However, the rain shortage pattern is clear enough, and, as the phenomenon lasts one year, it can be considered as its own predictor. Moreover, the deepest shortage occurs in November during the dry season, roughly six months after the appearance of an El Niño event. At this time, the drought is the most dramatic. Consequently, the eventual disasters associated with the drought could be forecasted six months in advance.

On the other hand, an interesting six-month delay can also be noticed between the drought peak in Indonesia occurring in May of an ENSO year (Quinn et al. 1978) and the New Caledonia peak, suggesting an eastward propagation of the phenomenon in the Southwest Pacific. An extension of the EOF analysis to the whole Southwest Pacific area, as already done for Australia (Pittock, 1975), would be useful, and, in particular, the use of individual rainfall composites might give interesting information on the mechanisms of propagation or of extension of climatic anomalies in this area.

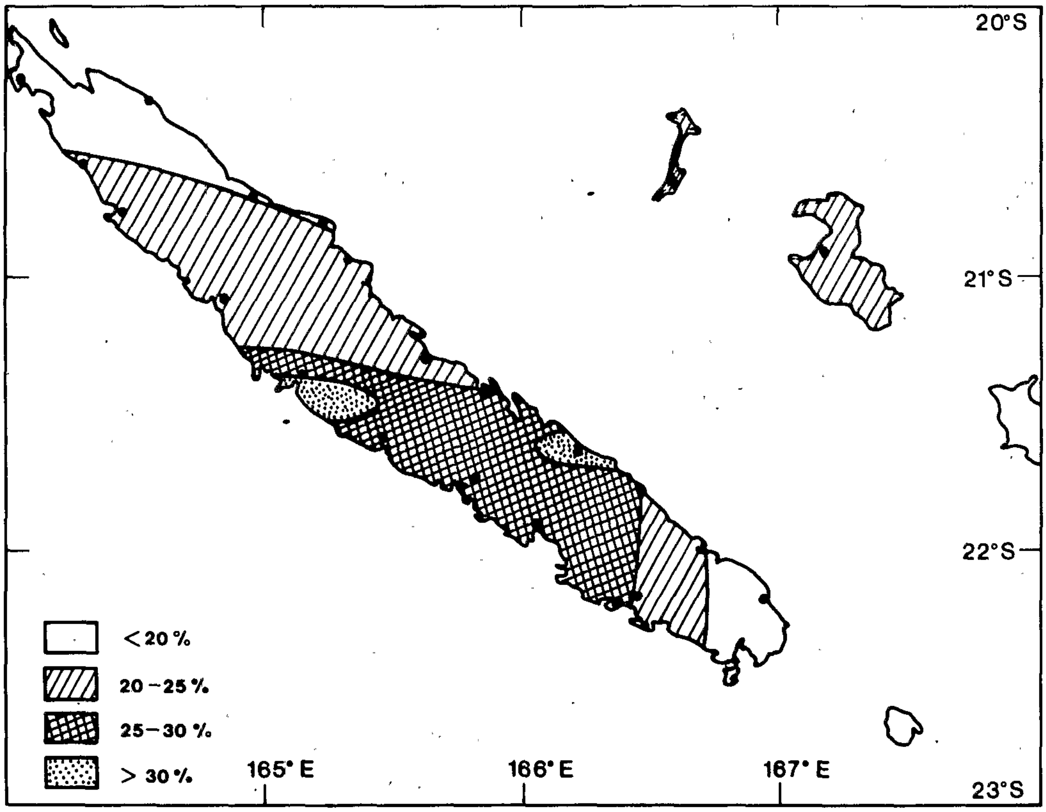

FIG. 6. Departure of the mean monthly rainfall in negative percentage during an El Niño year (for April ENSO to April ENSO + 1) computed for the total number of ENSO events having occurred during each station's rainfall record (8–18).

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