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EFFECTS OF EL NIÑO ON PANAMA RAINFALL

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RESUMEN

El efecto de "El Niño" en la lluvia sobre Panamá ha sido estudiado, utilizando trece episodios de "El Niño" durante el período de 1920 a 1983. Los resultados muestran que "El Niño" induce precipitación bajo lo normal en casi todas las regiones de Panamá. El promedio anual de la anomalía de precipitación durante todas las ocurrencias de "El Niño" es del 8% por debajo de lo normal. Para el caso de episodios de "El Niño" intensos de los años 1976 y 1982, las anomalías fueron de 28 y 24% por debajo de lo normal, respectivamente. El mes más seco del año 1982 (diciembre) tuvo una anomalía de precipitación del 60% por debajo de lo normal. Además, los resultados del estudio mostraron que hay una variación geográfica considerable en las anomalías de precipitación. En el caso de "El Niño" de 1976, las mayores anomalías negativas estaban localizadas en el suroeste de Panamá, en el vertiente Pacífico de la cordillera central. Por otro lado, "El Niño" produjo efectos opuestos (anomalías positivas) en el vertiente Atlántico. Se estudió la relación entre las variaciones temporales de la anomalía de precipitación anual y las anomalías de la temperatura superficial del Océano Pacífico Oriental. Se encontró una alta correlación negativa entre las anomalías de precipitación y la temperatura oceánica de los meses anteriores. Esta alta correlación ha sido usada para desarrollar un método de pronóstico de precipitación a largo plazo.

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ABSTRACT

The effect of El Niño on the rainfall in Panamá has been studied. Thirteen episodes of El Niño during the period, 1920 to 1983, were analyzed. The results show that El Niño produces below normal rainfall in almost all regions of Panama. The average annual rainfall anomaly, based on all occurrences of El Niño, is 8% below normal. In the case of the strong El Niño episodes of 1976 and 1982, the corresponding anomalies are 28% and 24% below normal, respectively. The driest month of the year 1982 (December) has a rainfall anomaly of about 60% below normal. The results of the study also showed that there is a considerable geographical variation in the rainfall anomalies. In the case of the El Niño of 1976, the largest magnitudes of the negative anomalies are located in the southwestern part of Panama, just south of the central cordillera on the Pacific side. On the other hand, El Niño had the opposite effect (positive anomalies) north of the cordillera in the Atlantic coastal region. The relationship between the time variations of the annual rainfall anomalies and sea surface temperature anomalies in the Eastern Pacific was studied. A high negative correlation was found between the rainfall anomalies and the sea surface temperature anomalies during the preceding months. This high correlation has been used to devise a method for long range forecasting of rainfall.

1. INTRODUCTION

The relationship between the occurrence of El Niño and rainfall anomalies over many regions of the world is now fairly well established. Here, the term El Niño refers to warm episodes characterized by abnormally high temperatures of the sea surface along the South American Coast and in the equatorial sections of the Eastern Pacific. The typical duration of a warm episode is about one to two years while the average interval between successive episodes is about 4 to 5 years. There are variations in the amplitude, starting time, and the geographical distribution of the temperature anomalies. A composite showing an example of these time variations of the temperature, which is based on a previous study by Rasmusson and Carpenter (1982), is shown in Fig. 1. Their article describes in detail the evolution of warm episodes. According to their description, the typical episode begins with the appearance of positive sea surface temperature anomalies near the Peru-Ecuador coast about the beginning of the calendar year. The area covered by the anomalies, as well as the magnitude of the anomalies, increase during the next few months, and reach maximum values near the coast around April to June. The warm water spreads westward along the equator, covering the entire eastern and the central equatorial Pacific by the following autumn. At the beginning of the succeeding year, negative sea surface temperature anomalies usually begin to appear near the South American Coast. These negative anomalies then spread westward along the equator in a similar manner as the warm anomalies ex-

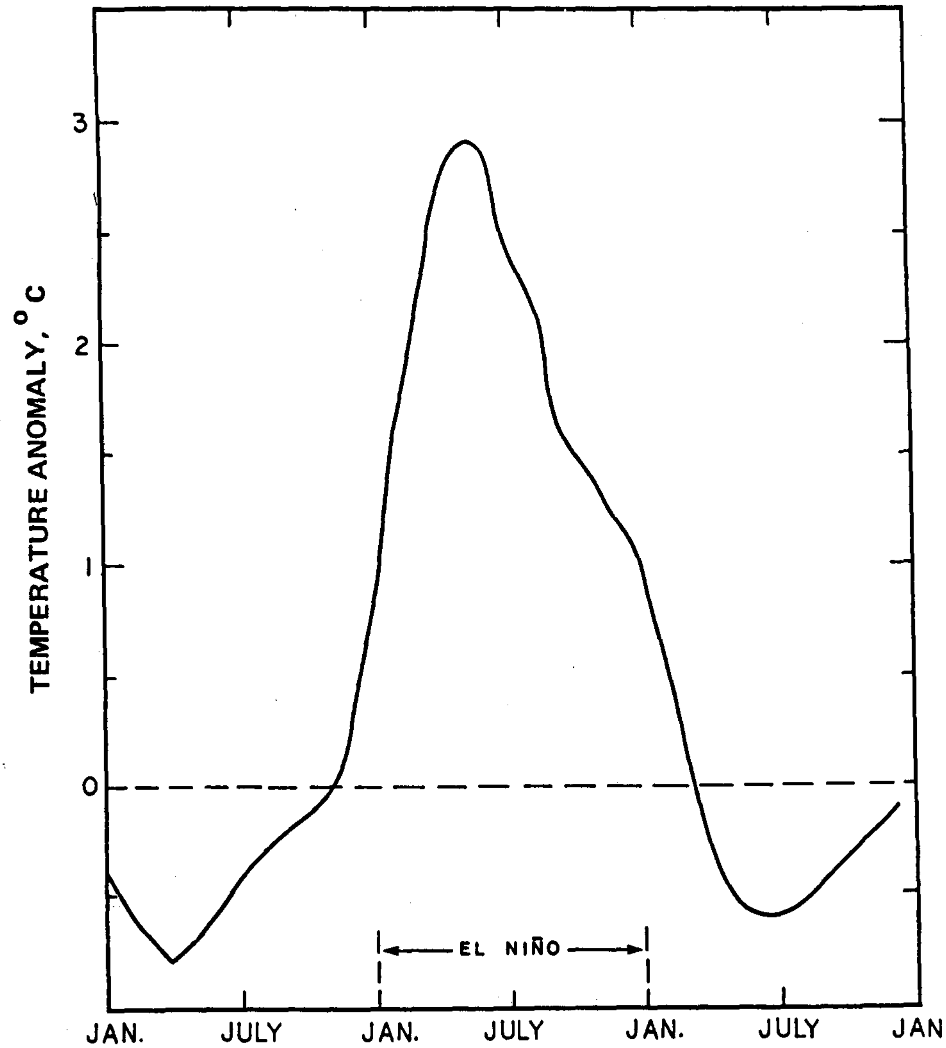

Fig. 1. Composite sea surface temperature anomalies corresponding to six El Niño years (After Rasmusson and Carpenter, 1982) along the northwestern coast of South America.

tended in the previous year. In a few cases, the warm anomalies persist for relatively long periods, such as in the El Niño years of 1957 and 1982.

The occurrence of warm episodes produces profound large-scale anomalies in rainfall. For example, these episodes are accompanied by below normal rainfall in India and in Indonesia (Rasmusson and Carpenter, 1983), Australia and New Guinea. On the other hand, these episodes produce above normal rainfall in Sri Lanka (Rasmusson and Carpenter, 1983), Peru, Ecuador and the Central Pacific. According to previous studies by Ramage (1975) and others, the rainfall anomalies in the Central and the Eastern Pacific are associated with the anomalous southern displacement and the intensification of the intertropical convergence zone. The above normal rainfall over Peru and Ecuador is presumably related to the abnormally warm waters off the South American Coast which promotes the development of convective disturbances. It is interesting to note that Ramage (1975) found large negative rainfall changes in the regions east of 120°W where the largest warm anomalies also occur. This region of below normal rainfall could presumably include Panama and the neighboring countries of Central America. However, his diagrams showing the frequency of highly reflective clouds for December 1971 and 1972 are not very definitive about this matter.

The object of this study is to determine the effect of El Niño (warm episodes) on Panama rainfall. The regional variation of these effects as well as their dependence on the intensity of the El Niño are studied. It is shown that the El Niño produces much below average rainfall during the rainy season, May to December. The magnitude of the negative rainfall anomalies is characterized by strong regional variations in Panama.

2. DATA AND ANALYSIS

The climatological nature of the present study requires reasonably long periods of observations of rainfall and sea surface temperatures. Fortunately, in the case of rainfall, Panama has some stations which have been observing rainfall for periods of as much as sixty to ninety years. Most of these stations are located in the vicinity of the Panama Canal. In the case of sea surface temperatures, the data which are used in the study, are based on diagrams presented in an article by Rasmusson and Carpenter (1982). Among the diagrams, the most important one is that which presents a time series of sea surface temperature anomalies for the period, 1921 to 1976. These anomalies correspond to observations near the coast of Peru and Ecuador. Unfortunately, the time series is interrupted; observations are missing during the period 1939 to 1948.

The existence of the longest period of observations in the Panama Canal area dictated that we concentrate our analysis of rainfall data from the Panama Canal watershed. A total of twenty seven stations are presently in operation in the watershed; the network of stations is shown in Fig. 2.

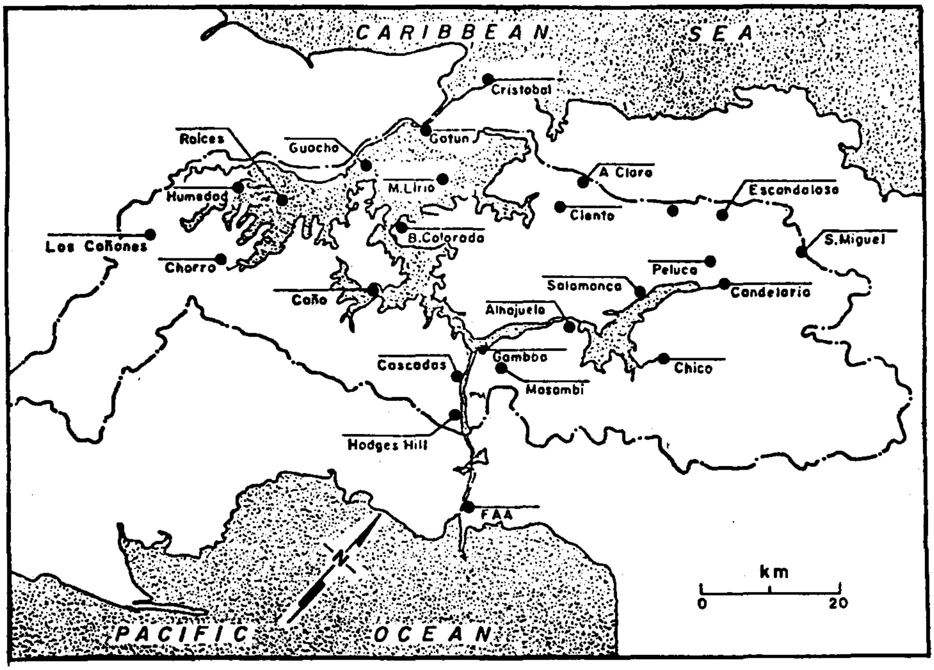

Fig. 2. Map showing the rainfall observational network in the Panama Canal area. Stations are indicated by black dots.

We selected five of the stations with relatively long periods of observations for much of our analysis. These stations, together with their periods of observations are:

Cristóbal (1890 - 1983), Alhajuela (1900 - 1983),
Balboa Heights (1906 - 1983), Gamboa (1897 - 1983),
Portobelo (1919 - 1983).

It may be mentioned that these stations are distributed more or less along the Panama Canal area: Atlantic Section (Cristóbal and Portobelo), Central Section (Gamboa and Alhajuela), Pacific Section (Balboa Heights).

The additional rainfall data which are used in our study come from a station network covering the rest of the country. This network, which is operated by the Department of Hydrometeorology, Instituto de Recursos Hidráulicos y Electrificación, is shown in Fig. 3. There are approximately two hundred and sixty stations. Most of the stations are located in the Pacific region of the country, south of the Central Cordillera. Large sections of the country, especially in the northern and the northwestern regions, still have an insufficient density of stations.

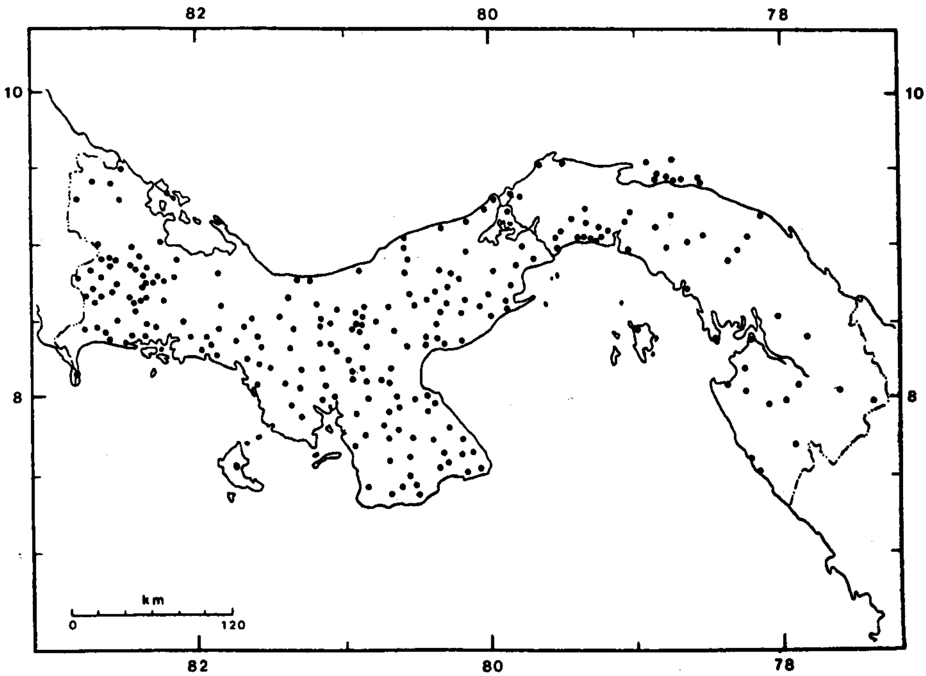

Fig. 3. Map showing the rainfall observational network over the entire country. Stations are indicated by black dots.

The majority of the stations in Panama have observations for relatively short periods of about 8 years. A small number of stations have been in operation for periods from 35 to 45 years. Others have been established recently, having somewhat less than 5 years of observations.

For the purpose of the data analysis to determine the regional variations of rainfall, we divided the entire country into five regions. These are the southwest region of Chiriquí and Veraguas, the dry region of Azuero and Coclé, the northwest region of Bocas del Toro, and the eastern region which includes Panama province, the Panama Canal area, and San Blas. The regions are indicated in Fig. 4.

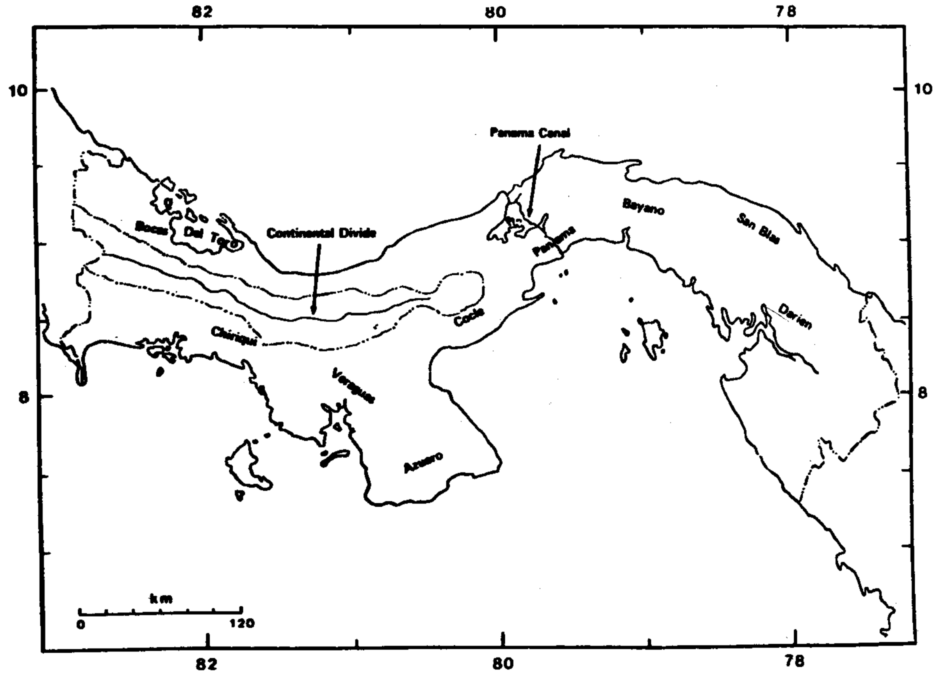

Fig. 4. Maps showing the different rainfall regions of Panama.

The primary method of analysis is the compositing method. The anomalies of rainfall during three year periods centered at the El Niño or the warm episode year were composited. Composites were made of all El Niño years as well as for different regions in Panama. Composites were also made for two types (strong and weak) of intensity of the El Niño year. In addition, maps were analyzed which show the geographical variations of rainfall anomalies in Panama. Finally, a correlation analysis was made to determine the relationship between rainfall and temperature anomalies.

3. RESULTS OF ANALYSIS

In order to portray the general relationships between rainfall variations in Panama with warm episodes, we present Fig. 5. The diagram shows values of the monthly rainfall anomalies in Panama during the period, 1921 to 1976, and the corresponding temperature anomalies. The values are computed by averaging the rainfall observations from the five stations at various locations from the Pacific to the Atlantic Coasts along the Panama Canal area mentioned in the previous section. The

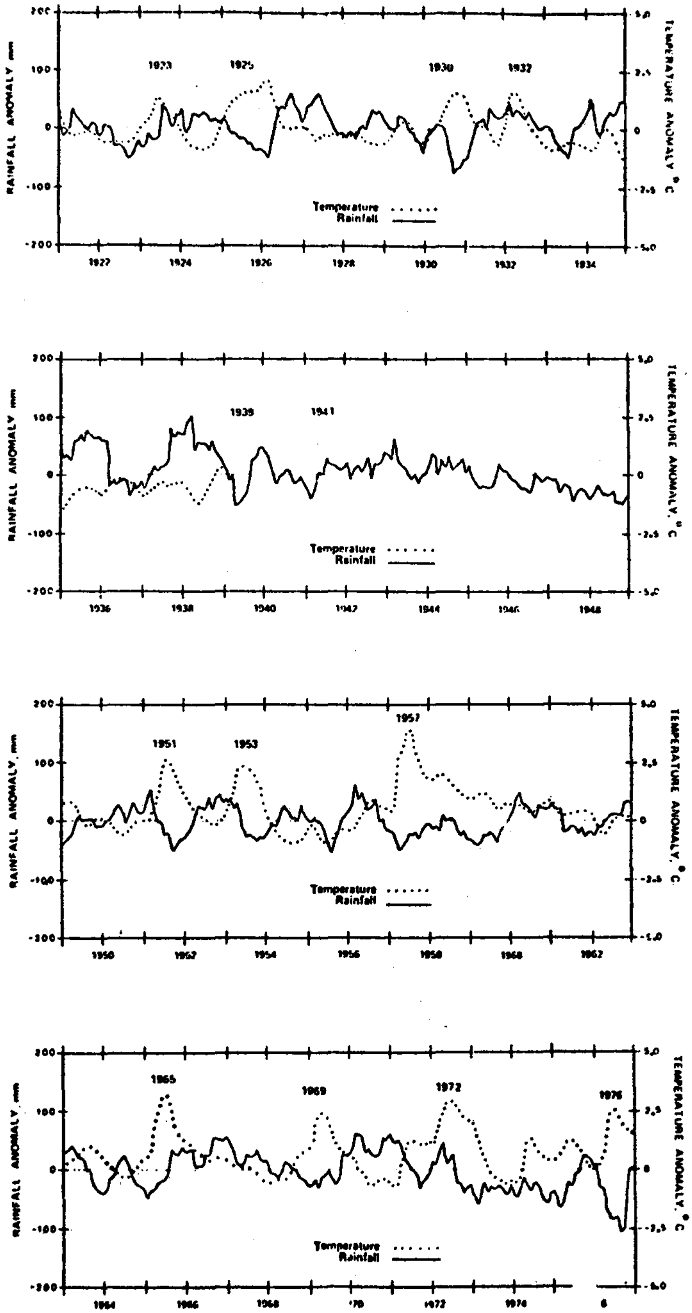

Fig. 5. Time variations of rainfall anomalies in the Panama Canal area and sea surface temperature anomalies along the northwestern coast of South America. Rainfall, full lines; temperature, dotted lines.

temperature curve represents corresponding temperature anomalies in the vicinity of the South American Coast. The anomalies are based on a diagram in the article by Rasmusson and Carpenter (1982). No temperature observations are available from the period 1939 to 1948. The warm episode years obtained from Rasmusson and Carpenter (1983) are also indicated on the diagram. It may seem that, with a few exceptions, the warm episode years are generally associated with below normal rainfall. One glaring exception to this association is the warm episode year of 1932 when above normal rainfall occurred. In this connection it may be mentioned that rainfall over Djakarta (Indonesia) for the

TABLE 1

RANKED ANOMALIES OF ANNUAL RAINFALL (STATIONS IN THE AREA OF THE CANAL)

No.	Ano. %	Year	Occurrence*	No.	Ano. %	Year	Occurrence*
1	-30	1976	0	28	- 1	1953	0
2	-27	1930	0	29	- 1	1965	0
3	-24	1982	0	30	- 1	1941	0
4	-20	1940	+1	31	0	1945	
5	-17	1948		32	+1	1959	
6	-16	1957	0	33	+2	1931	+1
7	-15	1980		34	+4	1963	
8	-15	1958	+1	35	+5	1934	
9	-15	1947		36	+5	1943	
10	-14	1977	+1	37	+5	1967	
11	-12	1946		38	+6	1932	0
12	-10	1939	0	39	+6	1952	+1
13	-10	1936		40	+7	1949	
14	-10	1968	-1	41	+8	1975	-1
15	-10	1979		42	+9	1942	+1
16	-10	1974		43	+9	1955	
17	- 9	1971	-1	44	+11	1944	
18	- 9	1983	+1	45	+12	1954	+1
19	- 7	1972	0	46	+13	1950	-1
20	- 7	1964	-1	47	+13	1956	-1
21	- 7	1961		48	+18	1937	
22	- 7	1933		49	+20	1966	+1
23	- 6	1973	+1	50	+21	1938	-1
24	- 5	1978		51	+26	1981	+1
25	- 4	1962		52	+28	1970	-1
26	- 3	1969	0	53	+36	1935	
27	- 2	1951	0				

* 0 = Year of El Niño
+1 = The year after El Niño
-1 = The year before El Niño

same year (January to April) is anomalously high. Usually, El Niño years are also characterized by negative anomalies in Djakarta. It may also be mentioned that Quinn *et al.* (1978) list the 1932 case as a weak episode. Another interesting feature of the curves is that positive anomalies tend to be associated with negative temperature anomalies. A good example of this association is shown during the year 1935.

An alternative method of portraying the close relationship between the occurrence of below normal rainfall and El Niño is shown in Table 1. The rainfall observations used in constructing this table are obtained from all stations (No. of stations = 27) in the vicinity of the Panama Canal shown in Fig. 2. The table shows the ranked annual rainfall anomalies (% of normal) in descending order, starting with the largest negative anomalies. The fourth column (Heading: time of occurrence) indicates whether the year of occurrence is before the warm episode year (− 1), during the warm episode year (0), or after the warm episode year (+1). It may be noted that, except for the year 1932, all warm episode years are associated with negative rainfall anomalies. It may be seen also that there are several years of large negative rainfall anomalies which do not seem to be associated with El Niño, such as 1948, 1980 and 1947. According to the report by Arkin *et al.* (1983), the year 1980 was characterized by warm temperature anomalies of at least +1°C and may therefore be classified as a warm episode year. In the case of 1947 and 1948, no sea surface temperature anomalies are available from previous studies and it is not possible to say definitely whether these years are indeed not characterized by positive sea surface temperature anomalies. It is interesting to note the year (1935) with the largest positive rainfall anomaly of +36% is associated with negative temperature anomalies (see Fig. 5). This is also the case for the years, 1938 and 1970. However, the third year from the bottom of the table (1981) does not appear to be associated with significant negative temperature anomalies on the basis of diagrams presented by Arkin *et al.*, 1983.

In order to determine the general characteristics of the rainfall variation due to the El Niño, we constructed a composite of the rainfall and the temperature anomalies by using all of the thirteen occurrences from 1923 to 1976. The resulting composite (Fig. 6) shows the time variation of the rainfall anomaly for a three-year period centered at the El Niño year. Also shown is the corresponding curve for sea surface temperatures. This curve is a composite of temperature observations at

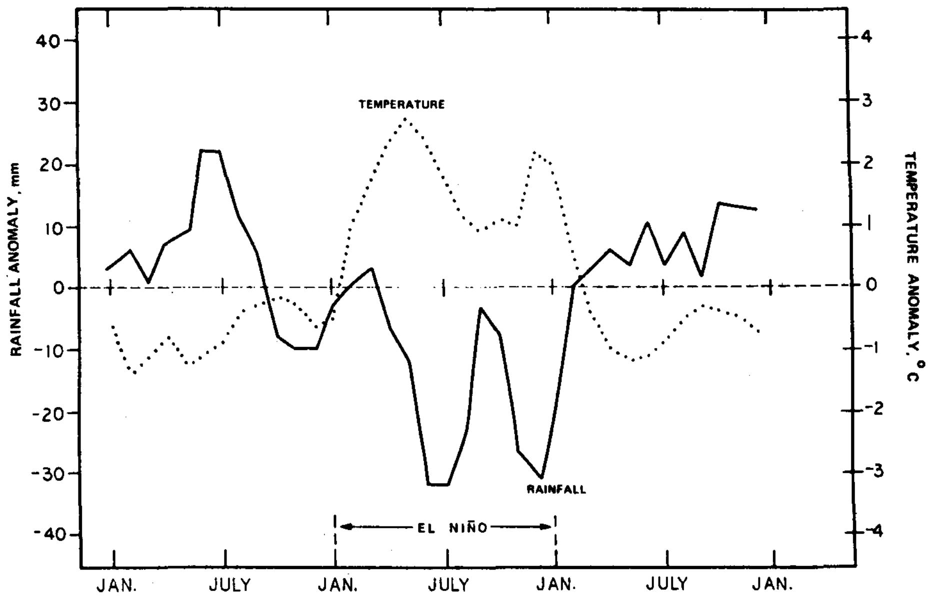

Fig. 6. Composite of rainfall and sea surface temperature anomalies. Rainfall anomalies correspond to observations in the Panama Canal area for thirteen El Niño episodes. Temperature anomalies corresponding to observations at Puerto Chicama (Peru) for six episodes.

Puerto Chicama for six warm episodes (1951, 1953, 1957, 1965, 1969, 1972) obtained from Rasmusson and Carpenter (1982). There are several interesting features of the rainfall curve: below normal rainfall during the El Niño year, above normal values in the middle of the preceding year, below normal values at the end of the preceding year, and above normal values during the succeeding year. In addition to these, one can see a very interesting smaller scale feature of the curve - the occurrence of a pronounced relative rainfall maximum in the period, September - October, of the El Niño year which represents an attempt of the rainfall to return to normal. The accompanying temperature deviation curve is almost a mirror image of the rainfall deviation curve. Note that, in general, the maxima in the temperature curve coincide with the minima in the rainfall curve. This coincidence is especially evident in the relative rainfall maximum which occurs in September to October of the El Niño year. From the point of view of rainfall forecasting, one notes that the rainfall minimum in July is preceded by a sharp rise in the temperature curve which starts in December, reaching a maximum near the end of May.

In order to illustrate the dependence of the rainfall on the intensity of the El Niño, we made a composite corresponding to four weak El Niño years (1932, 1951, 1953, 1969) and a composite corresponding to four strong El Niño years (1957, 1965, 1972, 1976). Included in these diagrams are corresponding sea surface temperature curves. These curves are computed from the time series for temperature observations in the vicinity of the South American Coast (SST (1)) presented by Rasmusson and Carpenter (1982); the observations are not for Puerto Chicama. Looking first at the composite for intense El Niño years (Fig. 7), one

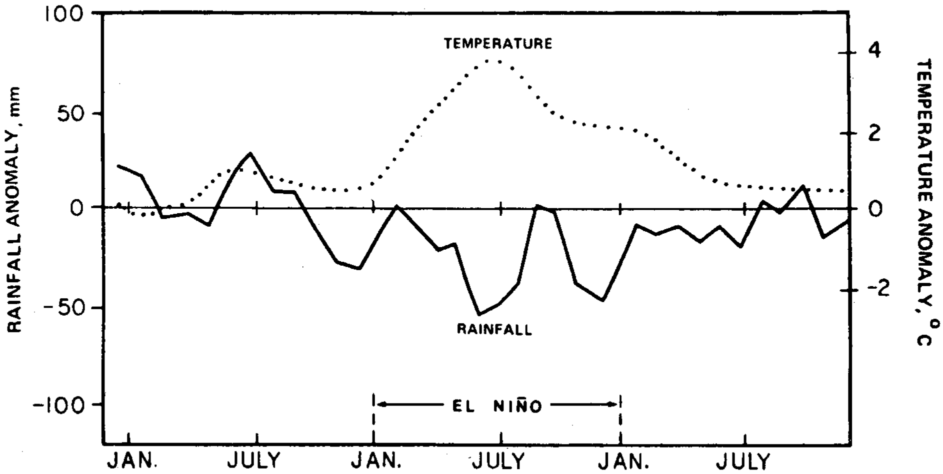

Fig. 7. Composite of rainfall and sea surface temperature anomalies for the intense El Niño episodes of 1957, 1965, 1972, 1976. Anomalies are based on values shown in Fig. 5.

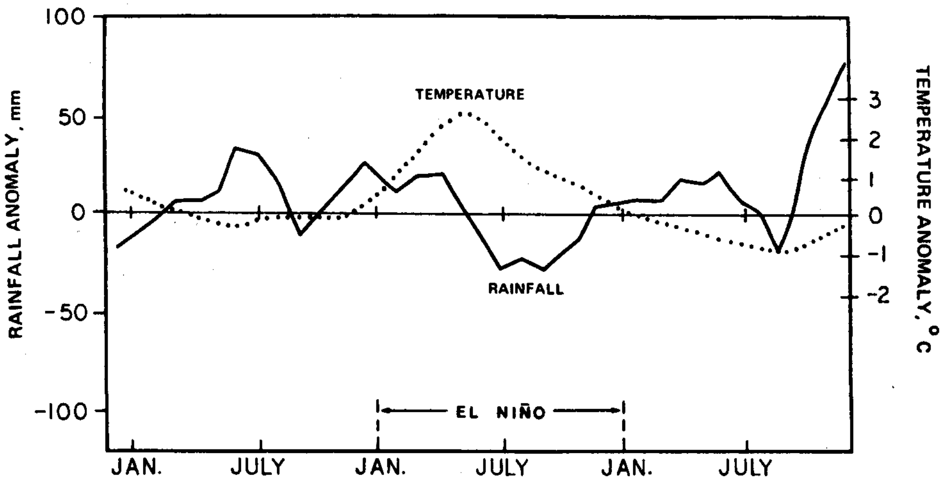

Fig. 8. Composite of rainfall and sea surface temperature anomalies for the weak El Niño episodes of 1932, 1951, 1952, 1969. Anomalies are based on values shown in Fig. 5.

can see that the rainfall curve has the same general characteristics of the corresponding rainfall composite for all El Niño years (Fig. 6). The relative maximum which occurs in September-October of the El Niño year is also present. In this case, however, the curve shows that the rainfall actually attains normal rainfall values, *i.e.* deviation is zero. The only significant difference between the two composites is that, in the case of the strong El Niño years, the rainfall anomaly remains negative in the year following the El Niño year. Looking at the case for weak El Niño years (Fig. 8), we see that the duration period of occurrence of the negative anomalies is shorter and the magnitudes of the anomalies are smaller. We see also that the tendency to return to normal values in September and October is not well defined. In addition, no significant negative anomalies occur near the end of the year preceding the El Niño year. Finally, it is interesting to compare these composites with corresponding curves of temperatures and rainfall for the unusually intense El Niño year of 1982 (Fig. 9). In this figure, the temperature anomaly curve is obtained from the diagram, (NIÑO 1 + 2), presented by Arkin (1983). This diagram is, in turn, based on operational data from the

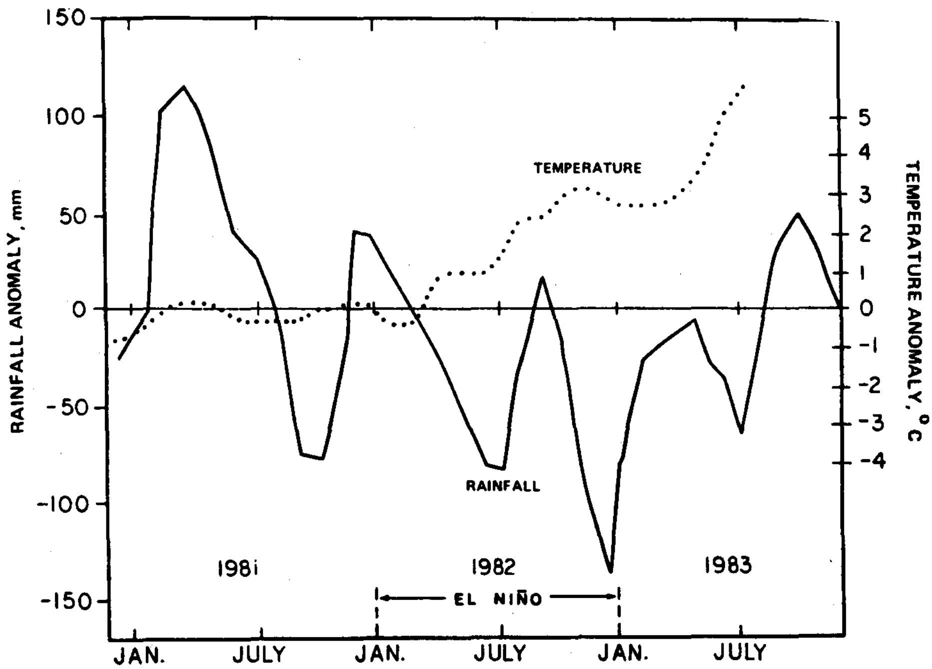

Fig. 9. Rainfall and sea surface temperature anomalies for the El Niño episode of 1982. Rainfall anomalies correspond to observations in the Panama Canal area. Sea surface temperatures are based on the report by Arkin *et al.*, 1983.

U. S. Climate Analysis Center. Therefore, the temperature curve may be considered as very preliminary in nature. Note that the amplitudes of the major rainfall variations range are approximately two to three times the corresponding amplitudes of the composite strong El Niño (Fig. 7). In the El Niño of 1983, it may be seen that the positive and the negative rainfall anomalies of the preceding year (1982) occur somewhat earlier than their counterparts in the composite strong El Niño. Note also the existence of the usual relative maximum in September and October; in this case, the maximum has overshot the normal value. Turning to the temperature curve, one can see that the usual tendency for it to be a mirror image of the rainfall curve as shown in Figs. 6 and 7 appears to be completely absent in this case. There is no apparent explanation. This absence could possibly be due to the fact that the temperature observations are operational in nature and may not be sufficiently accurate.

We will next consider the geographical variations of the rainfall anomalies produced by the El Niño in Panama. In this connection, we

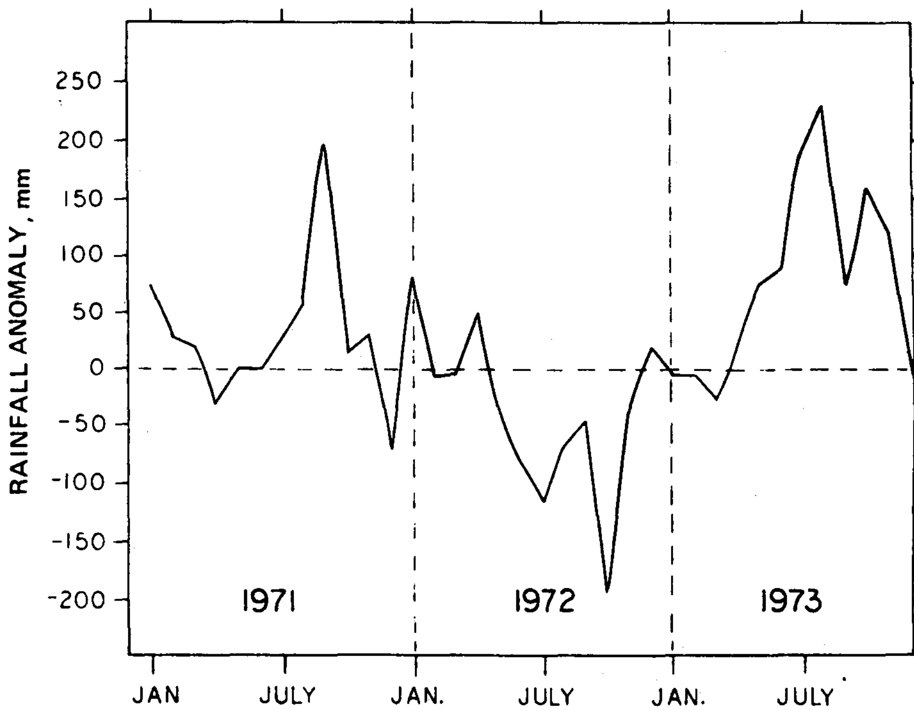

Fig. 10. Rainfall anomalies in the Chiriquí-Veraguas region for the El Niño episode of 1972.

analyzed the rainfall at various regions for the El Niño Years: 1972 and 1976. The regions are the Chiriquí-Veraguas region on the Pacific side of Southwest Panama, the Bayano region near the central part of Panama, and the Bocas del Toro region on the Atlantic side of Western Panama. Looking at the curves for 1972 corresponding to the Chiriquí-Veraguas and the Bayano regions (Figs. 10 and 11) one sees that the

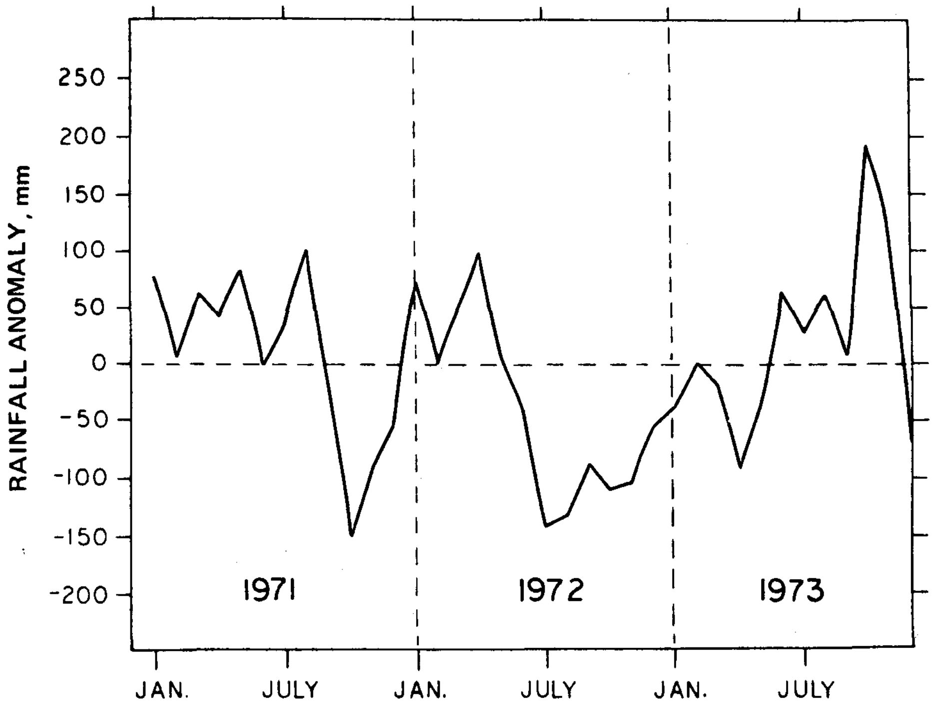

Fig. 11. Rainfall anomalies in the Bayano region for the El Niño episode of 1972.

variations in these two regions are generally similar. The only large differences are those observed in the year preceding the El Niño. The corresponding variations for these two regions but for the El Niño of 1976 are much more similar (Figs. 12 and 13). The same maxima and minima are reflected in both curves. The primary differences which may be seen involve the magnitudes of the maxima and the minima. In this connection, it is interesting to note the contrast in the magnitudes for the relative maximum in September and October of the El Niño year. The magnitude of this maximum for the Bayano curve is so large that the anomalies are positive over a two-month period. Comparing the curve for Bocas del Toro (Fig. 14) with these two previous curves (Figs. 12 and 13), we see that the primary difference is in the fact that the

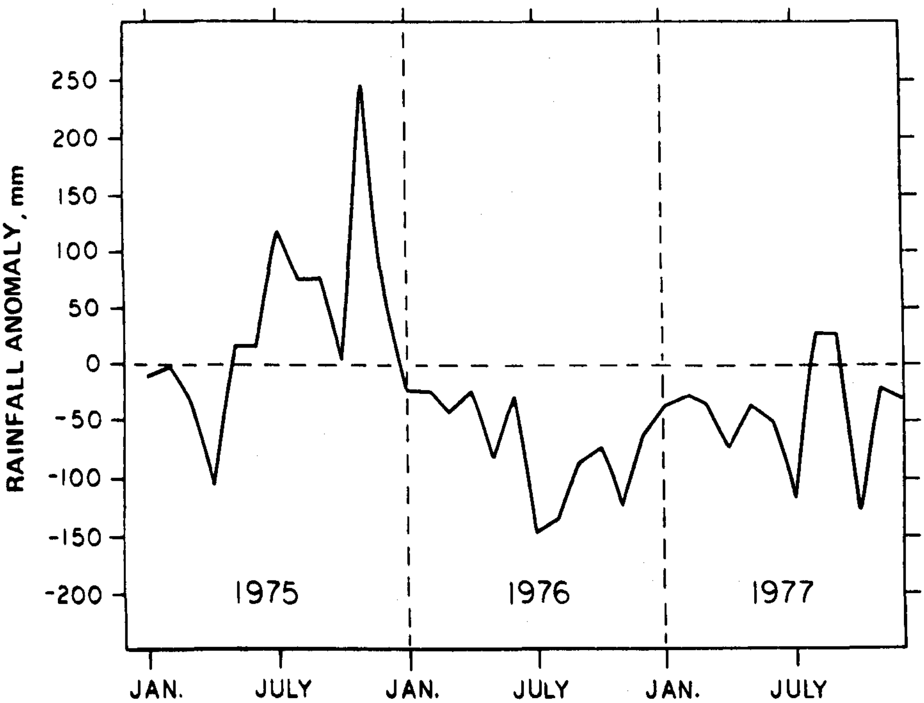

Fig. 12. Rainfall anomalies in the Chiriquí-Veraguas region for the El Niño episode of 1976.

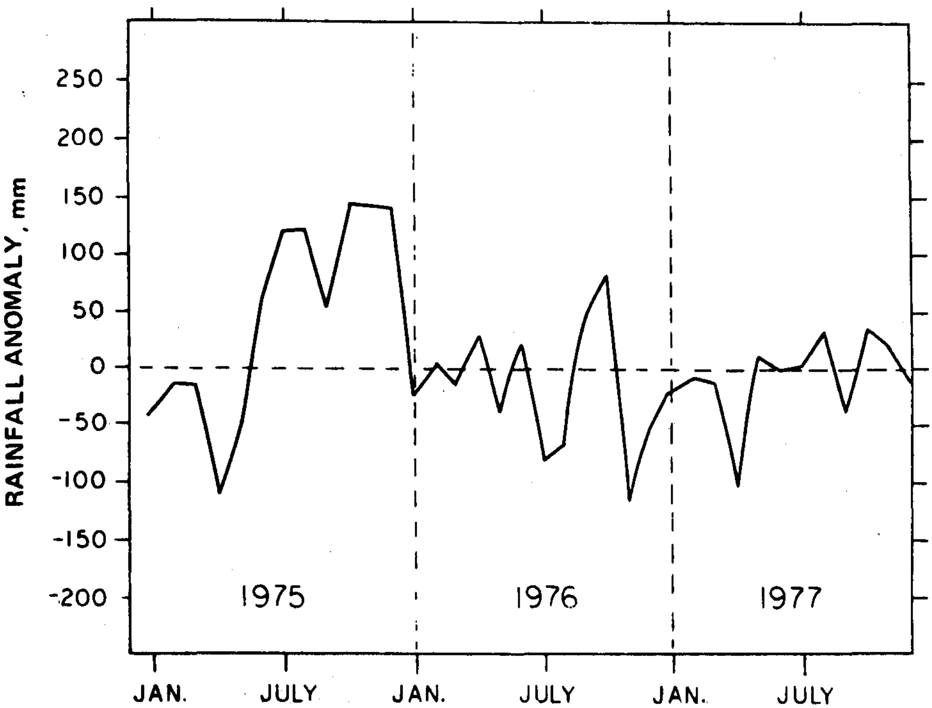

Fig. 13. Rainfall anomalies in the Bayano region for the El Niño episode of 1976.

rainfall anomalies for Bocas del Toro during the El Niño year are predominantly positive. In other words, the net effect for the entire year of the El Niño in the Atlantic Coast tend to be the opposite of that on the Pacific Coast. This tendency for the El Niño to produce opposite effects may be seen more clearly in Figs. 15 to 17. In these figures the distributions of the total rainfall anomaly for each of the years 1975, 1976 and 1977 are presented. The anomalies are expressed as percentages of the normal yearly rainfall. Looking first at the anomalies for the El Niño year 1976 (Fig. 16), we see the expected negative anomalies throughout most of the country except for a small area of positive anomalies in the Northwest part of Panama (Bocas del Toro region). The largest negative anomalies (−40%) tend to concentrate along a belt just south and on the Pacific side of the Central Cordillera. There are also comparable negative anomalies on the Azuero Peninsula located near 80°W meridian. In the preceding year of 1975 (Fig. 15), these regions of large negative anomalies were regions of positive anomalies; these positive anomalies are primarily associated with the above normal rainfall during the middle of the year as seen in Fig. 6. The pattern of anomalies for the year after the El Niño (Fig. 17) is generally similar to

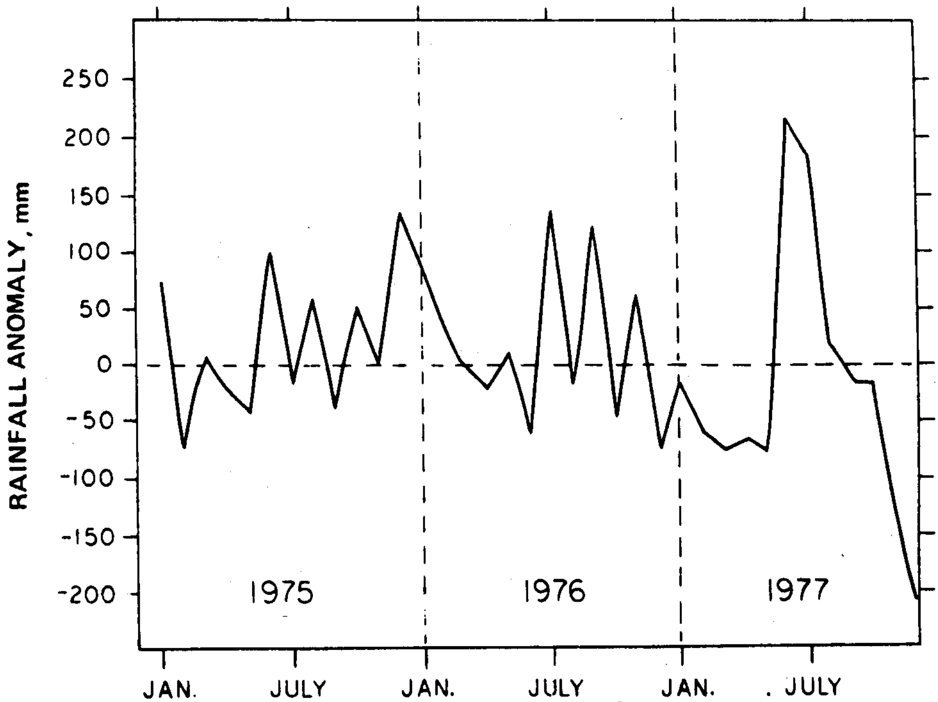

Fig. 14. Rainfall anomalies in the Bocas del Toro region for El Niño episode of 1976.

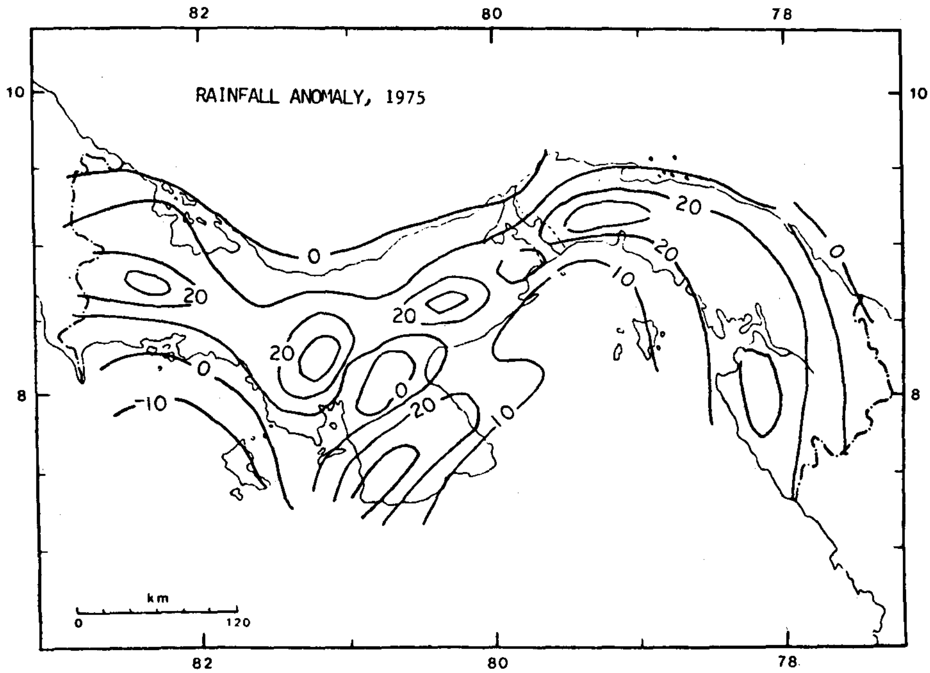

Fig. 15. Geographical distribution of rainfall anomalies (percent) during the year preceding the El Niño (1975).

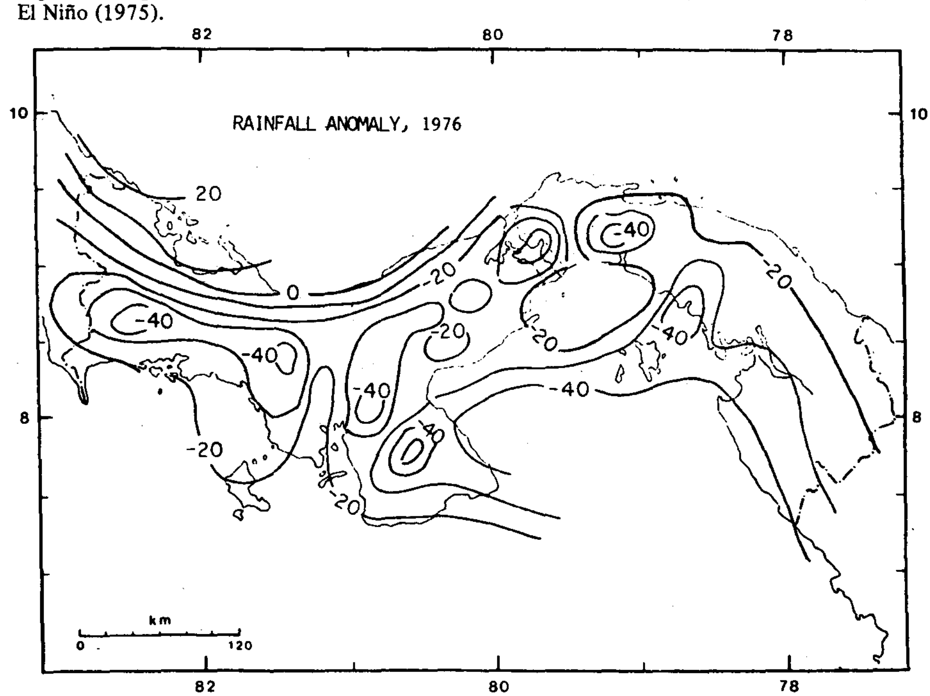

Fig. 16. Geographical distribution of the rainfall anomalies (percent) during the year of the El Niño (1976).

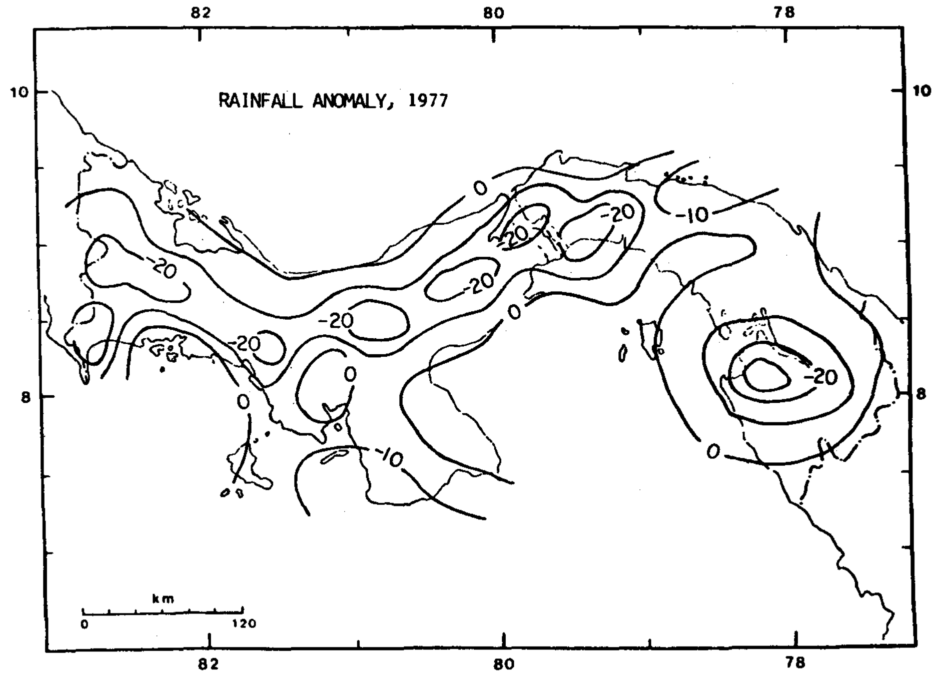

Fig. 17. Geographical distribution of the rainfall anomalies (percent) during the year following El Niño (1977).

that of the El Niño year. The main difference is that the magnitudes of the anomalies have been reduced to about half of the corresponding magnitudes for the El Niño year.

4. FORECASTING IMPLICATIONS

An important goal for conducting the present study is to determine the possibility of using the results for forecasting rainfall anomalies in Panama during the rainy season (May to December). Previous studies, such as the one by Rasmusson and Carpenter (1982), indicate that various events occur a few months before and at the beginning of the El Niño year. Hence, these events may be used for forecasting. Some of the better known ones are:

1. Positive rainfall anomalies in the Central Equatorial and the Eastern Equatorial Pacific
2. Negative rainfall anomalies over most of Indonesia
3. Negative pressure anomaly in Easter Island and a sharp rise in pressure in Darwin (Northern Australia)

(4) Anomalous westerly and northwesterly winds in the Pacific Ocean South of 10°S

(5) Development of positive sea surface temperature anomalies west of Chile, along the Ecuador-Peru Coast, and the Eastern Pacific.

Among these possible predictors, we have so far examined the predictive potential of temperature, Item (5). There are two characteristics of the sea surface temperature variation which appear to be of great prognostic value: (1) the magnitude of the positive temperature anomaly in April (T'_2) and (2) the amount of the increase in temperature from the preceding December temperature anomaly (T'_1) to the April temperature anomaly (T'_2) *i.e.* $T'_2 - T'_1$. The prognostic value of these two parameters is clearly indicated in Fig. 6 which shows that large positive values of T'_2 and $T'_2 - T'_1$ precede large values of negative rainfall anomalies. It is to be noted that both parameters have been chosen because

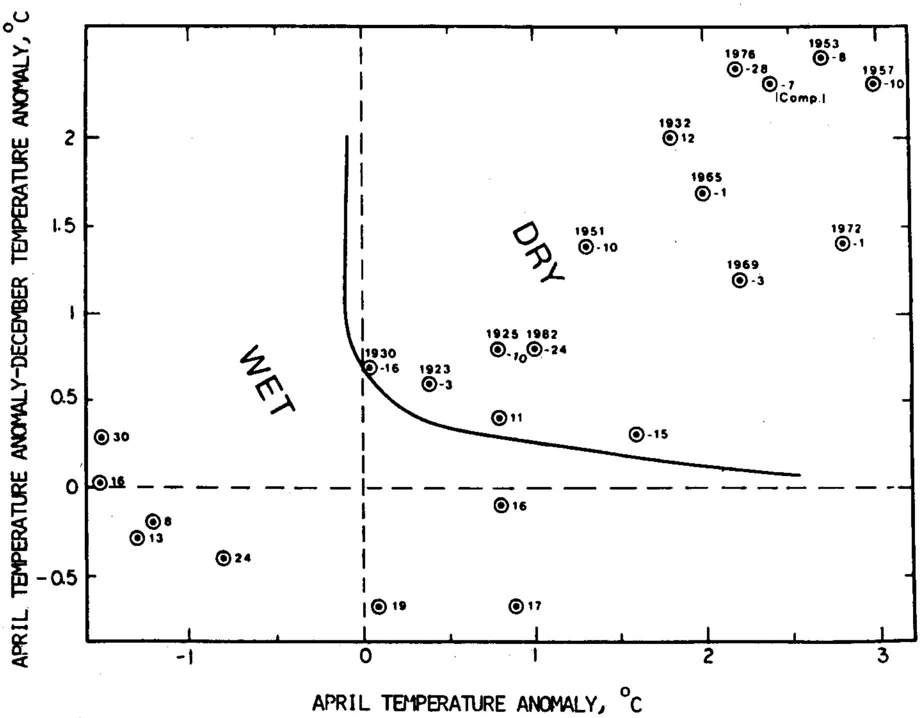

Fig. 18. Diagram showing the relationship between the annual rainfall anomaly (percent), the mean April temperature anomaly, and the mean April temperature anomaly minus the mean December temperature anomaly.

they are available before the beginning of the rainy season in Panama; therefore, they are useful for forecasting the rainfall for that season. In order to test the predictive value of these two predictors, we constructed the scatter diagram shown in Fig. 18. The data used for this diagram are based on the same ones used for constructing the two curves for rainfall and temperature in Fig. 5. It would have been preferable to use sea surface temperatures from Puerto Chicama instead of temperatures based on ship observations in the more extensive coastal areas of South America. The reason for this preference is because Puerto Chicama temperatures would give earlier indications of the occurrence of the El Niño. However, these were not available for our study. In Fig. 18, the abscissa is T'_2 while the ordinate is $T'_2 - T'_1$. Using the observed values of T'_2 and $T'_2 - T'_1$, we plotted the points corresponding to the El Niño years. Beside each point, we also plotted the corresponding rainfall deviation for the year (percentage of normal rainfall) and the year of occurrence. In addition to plotting the El Niño year, we plotted the composite or average of all the El Niño years (indicated by Comp.). We also plotted points corresponding to years whose annual rainfall deviations are at least 7% in absolute magnitude; for these points, only the deviations are plotted beside the point. We now proceed to examine the resulting diagram in Fig. 18. We note that, in general, the area inside the diagram may be separated into two regions. The first region includes most of the upper right hand quadrant; it corresponds to a region characterized by mostly positive temperature anomalies ($T'_2 > 0$) and rising temperatures ($T'_2 - T'_1 > 0$). With the exception of two cases, every point in this region is characterized by negative anomalies. One of the exceptional cases corresponds to the strange year 1932. All El Niño years are found in this region. The second region, which corresponds to the rest of the area in the diagram, contains only points corresponding to years with annual rainfall greater than normal (positive anomalies). We had expected that isolines of equal values of anomaly could be drawn such that the isolines with the most negative anomalies would lie near the upper right hand corner of the diagram where the values of T'_2 and $T'_2 - T'_1$ are largest. Unfortunately, this was not possible because there is some randomness in the distribution of the anomalies. There are two possible factors which may produce this randomness. First, the temperature as well as the rainfall observations are either erroneous or not entirely representative. Second, the predictors, T'_2 and $T'_2 - T'_1$ may not be the only important controlling factors for the occurrence of rainfall deviations. Due to these factors, there are points in

Fig. 18 with relatively large negative values of the rainfall anomalies which are located near the origin (small values of T'_2 and $T'_2 - T'_1$). Note, for example, the El Niño of 1982 which has a large negative rainfall anomaly of −24%; however, the corresponding point in Fig. 18 lies relatively near the origin. In this case, the reason for this surprising location is because the increase in the temperature anomaly occurred late as indicated in Fig. 9. This is also the same reason for the El Niño of 1930 (anomaly = −16%) whose corresponding point lies close to the line, $T'_2 = 0$. Obviously, this type of deficiency could be minimized by redefining T'_2 and T'_1 so that they correspond to months other than April and December.

It may also be noticed that there are points which are located near the upper right hand corner (*e.g.* 1972) and which are characterized by only small negative rainfall deviations. The reason for the unexpected location in this case is largely due to the fact that relatively large positive rainfall anomalies occurred during the dry season (January to April). These large positive anomalies partially counteracted the large negative anomalies which occurred during the following rainy season. The net effect is to produce relatively small negative anomalies. It would be interesting to construct a diagram similar to Fig. 18 but using the rainfall anomaly only for the rainy season (May to December) instead of for the entire year (January to December). Another reason for the small value of the negative rainfall anomaly is the lack of areal representativeness of the rainfall observations. For example, if one computes the anomaly for the year 1972 using all 27 stations instead of only 5 stations in the Canal area, the resulting anomaly is equal to −7%. This value is more reasonable than the −1% if one considers that the location of the point is close to the upper right hand corner in Fig. 18.

An alternative way of relating the rainfall anomaly to the predictors, T'_2 and $T'_2 - T'_1$ is by means of defining a temperature index, T.I. = $T'_2 + (T'_2 - T'_1)$. The rainfall anomaly is then plotted along the ordinate against T.I. as the abscissa. The results of such a plot are shown in Fig. 19. In this diagram, points which correspond to El Niño years are indicated by circles with the year written beside the point. As expected, we see that all the El Niño years which are characterized by negative anomalies, lie in the lower right hand corner. In other words, positive values of the temperature index are generally associated with negative rainfall anomalies. Note the unusual location of the strange El Niño

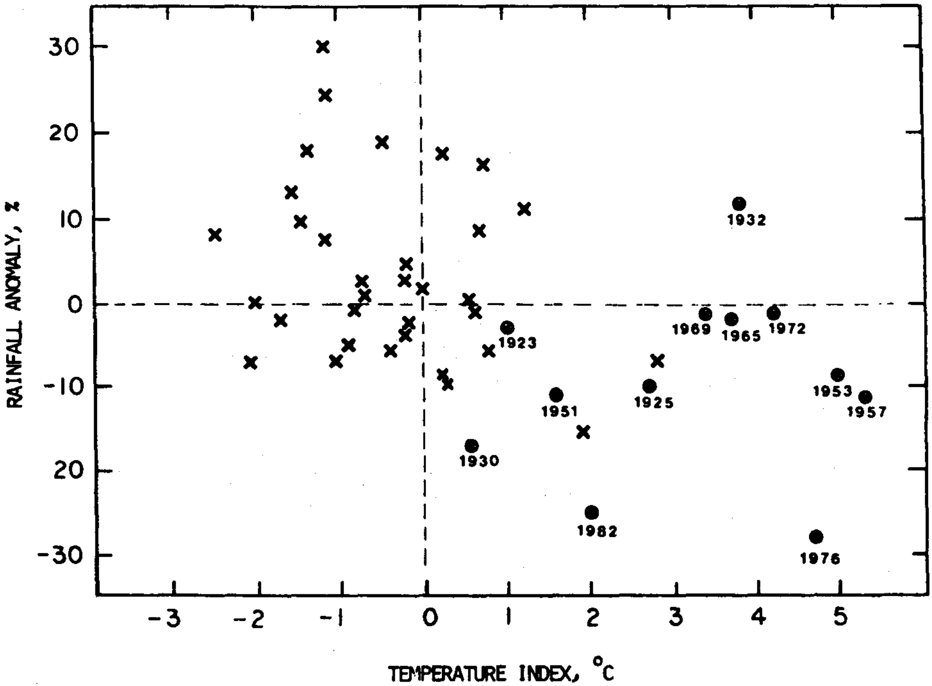

Fig. 19. Relationship between the rainfall anomaly for the year and the temperature index. For definition of the temperature index, see text.

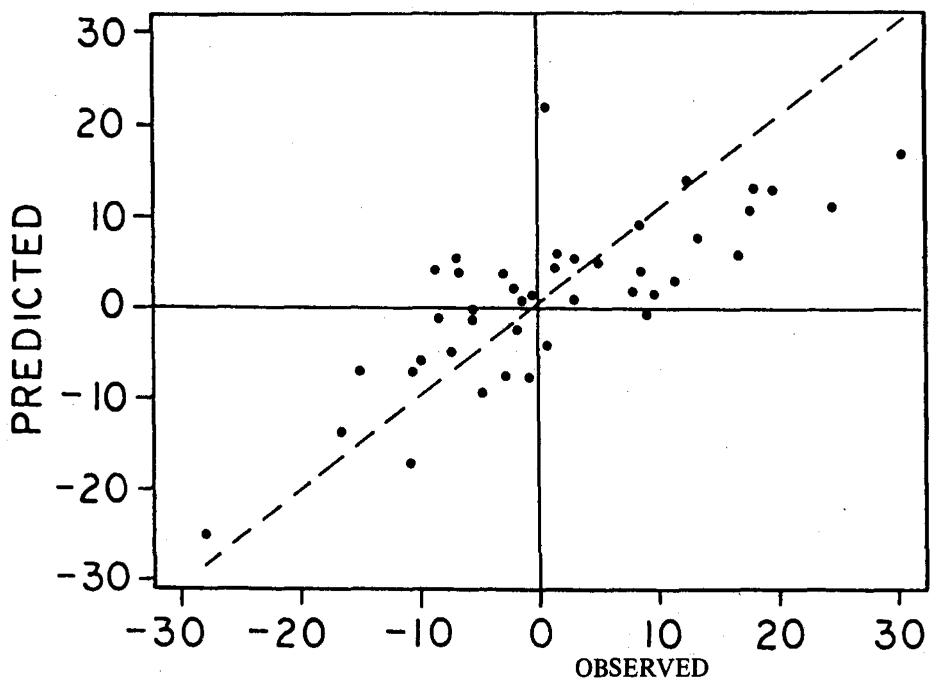

Fig. 20. Comparison between the predicted and observed rainfall anomalies (per cent) using a regression equation involving sea surface temperature anomalies.

year of 1932 in the upper right hand quadrant. Note also that, in general, above normal rainfall is associated with negative values of the temperature index. Thus, on the basis of this diagram, one can use the following rule for forecasting: if the temperature index is positive (negative), the total annual rainfall is below (above) normal. Using this rule, together with data in Fig. 20, we constructed the contingency table below:

	FORECAST	
	BELOW NORMAL	ABOVE NORMAL
BELOW NORMAL	17	8
ABOVE NORMAL	6	13

This table shows that, of the 23 forecasts for below normal rainfall (negative deviations), 17 forecasts were correct while 6 forecasts were wrong. Therefore, the percentage of accuracy is 17/23 or 74%. The corresponding numbers for forecasts for above normal rainfall are 13 correct and 8 wrong forecasts; the percentage of accuracy is 62%. It is seen that the forecasting rule is more accurate for predicting the occurrence of below normal rainfall.

The possibility of using temperature for forecasting has also been explored by means of a linear regression equation of the form:

$$R' = A_o + \sum_{n=1}^{10} A_n X_n$$

where R', is the annual rainfall deviation (%) while the x values are the temperature deviations for the ten consecutive months which begin in July of the preceding year. Forty five years of data were used for deriving the regression coefficients, A_0 to A_{10}. With the aid of these coefficients and the regression equation, we made predictions of R' using dependent data. A comparison between the predicted and observed values is shown in Fig. 20. We note that there is a fair agreement between the forecast and the observed rainfall deviations. The correlation coefficient between observed and forecast values is approximately 0.70.

5. DISCUSSION AND CONCLUDING COMMENTS

In this article, we have presented the results of a study concerning the effects of El Niño on rainfall in Panama. The results show that El Niño produces below normal precipitation. The average annual deviation for the Panama Canal area is 8% below normal for an El Niño of average intensity. In the case of the strong El Niño episodes of 1976 and of 1982, the corresponding values are 28% and 24% below normal, respectively. The driest month of the year 1982, December, has a rainfall of about 60% below normal. The results of these studies also showed that there is considerable geographical variation of the effects of the El Niño. In the case of the El Niño of 1976, the largest magnitudes of the negative deviations are located generally in the southwestern part of Panama, just south of the central cordillera. On the other hand, El Niño of 1976 had the opposite effect or positive rainfall anomalies north of the cordillera in the Atlantic coastal region. The occurrence of negative anomalies during El Niño years in Panama appears to be consistent with the idea that the intertropical convergence zone shifts its position southward during the El Niño years. The southward displacement of the intertropical convergence zone away from Panama, together with the fact that most rainfall in Panama is normally due to this zone of convergence, produces the negative rainfall deviations. This southward position, on the other hand, produces the positive rainfall anomalies over Peru and the surrounding areas. The abnormal position of the intertropical convergence zone (together with the associated pressure trough of relatively low wind speeds) far to the south would imply stronger northerly winds over Panama. As these northerlies cross the central cordillera from the Atlantic to the Pacific coasts of Panama, they lose their moisture over the windward side. Thus, the air arrives over the leeside (south of the cordillera) as a dry wind. This could explain the relatively large negative deviations over the Chiriquí-Veraguas region.

Scatter diagrams relating rainfall anomalies and sea surface temperature anomalies have been plotted. The diagrams show considerable value in the long-range prediction of rainfall for Panama. Finally, a regression analysis of the time series of the rainfall and the sea surface temperature deviations indicates a high correlation coefficient between the annual rainfall deviation and the values of the temperature deviations during the earlier months. Therefore, it would be possible to forecast the occurrence of below normal rainfall with some degree of success with the aid of regression equations involving previously observed temperature deviations.

The results of this study suggest several interesting extensions in the future. First, it would be desirable to extend the study of the rainfall effects of El Niño to other regions of Central America, Mexico, and the Pacific coastal regions of South America. Knowledge concerning the effects along the north-south direction from Mexico to Chile would be extremely valuable for understanding the basic nature of the El Niño and for long-range forecasting of rainfall. In particular, such a study would show the details of the transition of rainfall variations from regions with negative rainfall deviations in Panama (and presumably regions to the north) to regions of positive deviations in Peru. It would also show geographical variations of time lags between the times of occurrence of various effects of El Niño; this information would, in turn, be extremely useful for forecasting purposes. Second, it would be interesting to extend the study in order to analyze the relationships between El Niño and other meteorological variables, such as wind, temperature, and moisture at the surface and at upper levels. Lastly, it would be desirable to repeat pertinent aspects of the present study by using observations of sea surface temperature at Puerto Chicama and other coastal stations in Peru, Ecuador and Chile. The results of such a study would be extremely valuable for developing methods of long-range forecasting of Panama rainfall.

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