Predictability of Droughts and Floods Due to El Niño and La Niña Episodes

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ABSTRACT

The possibility of predicting rainfall anomalies in the Philippines due to El Niño and La Niña is studied. The data used consist of rain gauge observations, satellite-derived rainfall, and sea surface temperatures in the Central Pacific Ocean. The investigation is done in two steps. First, the evolution of patterns of rainfall anomalies associated with the El Niño episodes of 1982-83, 1987-88, and 1997-98 is examined by using satellite-derived rainfall. It is found that the anomaly patterns vary from one episode to another. This finding indicates that it is difficult to predict rainfall anomalies by extrapolation from patterns of previous El Niño episodes.

Next, correlations between sea surface temperatures and rainfall anomalies are analyzed for rain gauge stations in the Philippines. Simultaneous correlations between annual anomalies for temperatures and rainfall are computed. The highest correlation coefficient (about 70%) is obtained for Dumaguete. The lowest values are found for stations in Luzon. Lagged correlations (temperature values precede rainfall values) are also computed for seasonal anomalies. The results of the correlation analysis are used to develop regression equations for predicting rainfall from the sea surface anomalies. Tests of the equations using dependent data show that it is not possible to predict the occurrence of droughts or floods from the sea surface temperatures, except possibly for the station of Dumaguete. In general, one can conclude that El Niño sea surface temperatures alone are not sufficient for predicting droughts in the Philippines.

Key words: El Niño, La Niña, droughts, floods, sea surface temperature, prediction

INTRODUCTION

The climatological variations of rainfall in the Philippines are influenced significantly by El Niño and La Niña episodes. In general, El Niño episodes or the warm episodes of the El Niño-Southern Oscillation (ENSO) phenomenon are characterized by below normal rainfall in many regions. On the other hand, La Niña or cold episodes are associated with above normal rainfall. These rainfall abnormalities or anomalies produce adverse impacts on agriculture, water resources and other sectors of the economy of the country. In order to be able to mitigate the effects of these impacts, one should have accurate forecasts of the occurrence of these rainfall anomalies. More specifically, the forecasts should indicate the regions to be affected, the time periods of occurrence, and the magnitudes of the rainfall anomaly.

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There are, at the present time, only a few studies on the prediction of rainfall due to El Niño and La Niña episodes. However, numerous diagnostic studies have been made on the relationship between rainfall and sea surface temperatures (SST) associated with these episodes. Examples of such studies are those by Ropelewski & Halpert (1987), Uvo et al. (1998), Grimm et al. (1998), and Schonher & Nicholson (1989). These studies show strong relationships between ENSO and rainfall in many regions of the world. The strongest relationship is found over the tropical Pacific. This is indicated by the composites of rainfall anomalies in Fig. 1. The anomalies are deduced from outgoing long wave radiation data by Hoerling et al. (1997). The figure indicates that there is a pattern of negative rainfall anomalies centered over the Southern Philippines during El Niño episodes. On the other hand, positive rainfall anomalies occur over almost the same location during La Niña episodes.

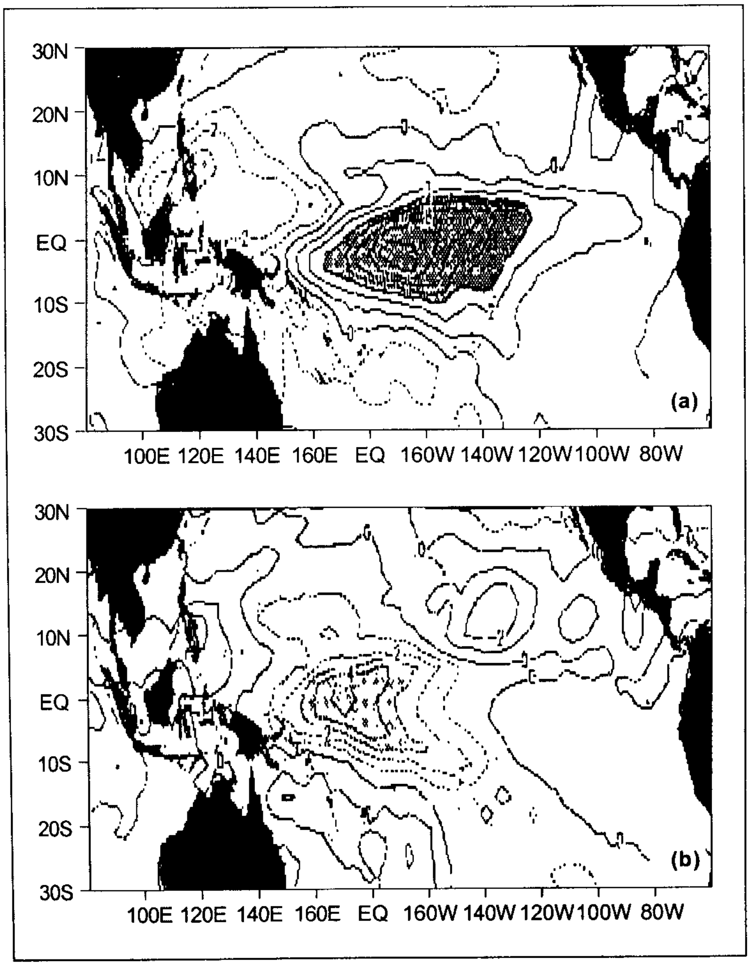

Fig. 1. Composite distribution of rainfall anomalies associated with (a) El Niño and (b) La Niña episodes averaged for the period December to January. Adapted from Hoerling et al. (1997).

With regard to the few articles which deal particularly with the prediction of rainfall anomalies, one can cite the studies of Estoque et al. (1985) and Montecinos et al. (2000). Estoque et al. developed a regression equation for the long-range prediction of Panama rainfall. The predictors are based on the sea surface temperatures over the Eastern Pacific for the months preceding the occurrence of the rainfall anomalies. On the other hand, Montecinos and his colleagues used canonical correlation analysis in order to determine the predictability of rainfall over subtropical South America. The predictor used is the Pacific sea surface temperature with a 3-month lag period. They found that the predictability is restricted only to certain seasons of the year and to some regions.

The present study examines the possibility of developing a method for predicting Philippine rainfall anomalies associated with the ENSO phenomenon. The first part of the study is an analysis of the relationships between rainfall anomalies and Central Pacific sea surface temperature. The second part involves the formulation of statistical prediction equations based on the results of the analysis.

MATERIALS AND METHODS

The data for the study consist of the following: (1) Rain gauge observations from the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA) synoptic stations; (2) Rainfall estimates from the National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) Reanalysis Project of the U.S. National Oceanographic and Atmospheric Administration (NOAA); and (3) SST from the Climate Prediction Center of NOAA.

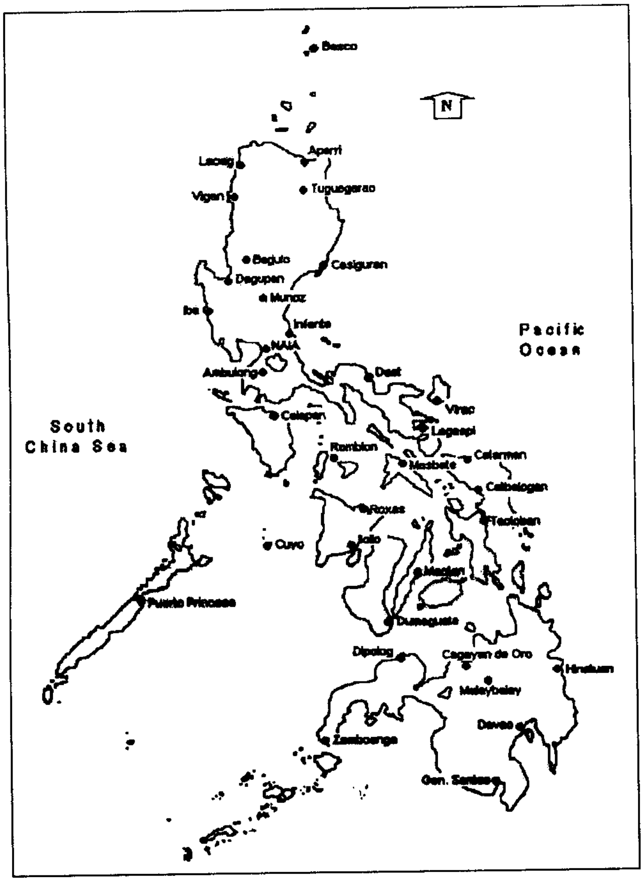

Fig. 2. Map of the Philippines showing the location of rain gauge stations.

Table 1. Quarterly values of the SST anomaly.

Year	JFM	AMJ	JAS	OND	Year	JFM	AMJ	JAS	OND
1950	-2	-2	-2	-2	1976	-2	0	0	1
1951	-2	0	0	1	1977	0	0	0	1
1952	0	0	0	0	1978	1	0	0	0
1953	0	1	1	0	1979	0	0	0	0
1954	0	0	-1	-2	1980	1	0	0	0
1955	-2	-1	-1	-3	1981	0	0	0	0
1956	-2	-2	-2	-1	1982	0	1	2	3
1957	0	1	1	2	1983	3	2	0	-1
1958	3	2	1	1	1984	-1	-1	0	-1
1959	1	0	0	0	1985	-1	-1	0	0
1960	0	0	0	0	1986	0	0	1	2
1961	0	0	0	0	1987	2	2	3	2
1962	0	0	0	0	1988	1	0	-1	-3
1963	0	0	1	2	1989	-3	-1	0	0
1964	0	0	-1	-2	1990	0	0	1	1
1965	-1	0	2	3	1991	1	1	2	2
1966	2	1	1	0	1992	3	3	1	1
1967	0	0	0	0	1993	1	2	2	1
1968	0	0	0	1	1994	0	0	2	2
1969	2	1	1	1	1995	2	0	0	-1
1970	1	0	0	-2	1996	-1	0	0	0
1971	-2	-1	-1	-1	1997	0	2	3	3
1972	0	1	2	3	1998	3	2	-1	-2
1973	2	0	-1	-3	1999	-3	-2	-1	-2
1974	-3	-2	-1	-1	2000	-2	-1	0	-1
1975	-1	-1	-2	-3	2001	-1	0	0	0

Legend:

JFM - January, February, March
AMJ - April. May, June
JAS - July, August, September
OND - October, November, December

The geographical locations of the rain gauge stations are shown in Fig. 2. The observations for the period from 1950 to 1996 are used. The NCEP-NCAR rainfall data are based primarily on satellite observations. More information about the data is given by Kistler et al. (2001). The values of rainfall anomalies are available at grid points (2.5 x 2.5 degrees). The SST data used correspond to a key region of the tropical Central Pacific Ocean. This region is located along the equator from 150 to 180 degrees west. The SST for this section corresponds approximately to that of Niño 3.4 in Fig. 3. Note that the SST anomalies for this region are less than those of the sections to the east. On the other hand, these are greater than those of Niño 4 to the west. Table 1 lists the intensity of the SST anomalies for every quarter of the year for the period 1950 to 2001 based on Item 3 above. In order to use the original data in the analysis, we replaced the letters C, N, and W by assigning numbers. The letters indicate C for cold, N for normal, and W for warm. The convention used is:

W+ = 3	N = 0	C+ = -3
W = 2	C- = -1	
W- = 1	C = -2	

RESULTS AND DISCUSSIONS

Relationships between observed rainfall anomalies

In order to develop statistical techniques for predicting the rainfall anomalies, one must have information about the relationships between these anomalies and the corresponding anomalies in the sea surface temperature. We examine, first, the large-scale features of these relationships over the Western Pacific for three major

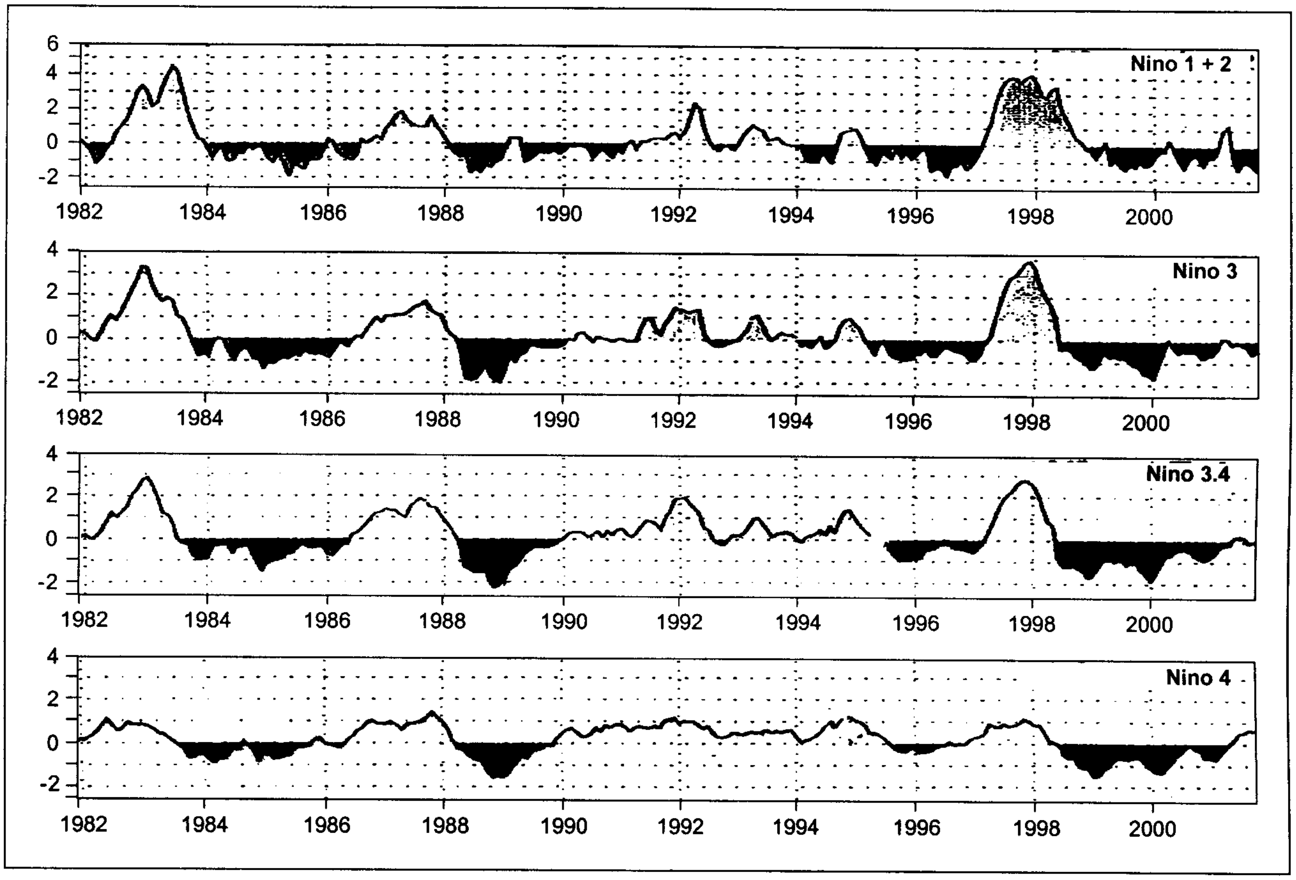

Fig. 3. Time variations of sea surface temperature anomalies over the Equatorial Pacific Ocean. Reproduced from the National Oceanographic and Atmospheric Administration (NOAA) Climate Diagnostics Bulletin of April 2002.

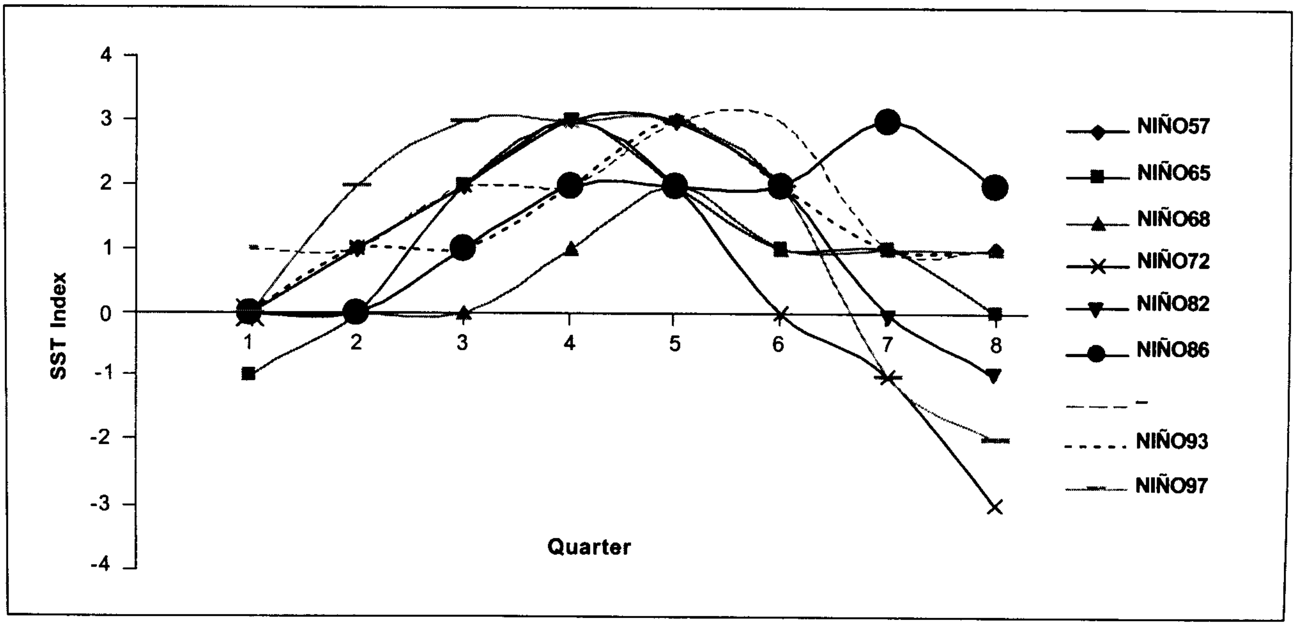

Fig. 4. Sea surface temperatures associated with different El Niño episodes based on Table 1. The major El Niño episodes (1982-1983, 1986-1987, and 1997-1998) which are analyzed are indicated by bold lines.

El Niño episodes – 1982-83, 1986-87, and 1997-98. The SST anomalies for these episodes are shown in Fig. 4, together with those of other episodes during the last fifty years. These anomalies are based on Table 1. It may be seen that there are large variations in the SST anomaly patterns associated with the different El Niño episodes. These large variations will presumably be reflected in correspondingly large variations in the rainfall anomaly patterns. These variations will be seen in Figs. 5 to 12. They show the time evolution of the rainfall anomaly patterns at four-monthly intervals for the three selected El Niño episodes. The periods correspond to the following: February to May, June to September, and October to January. They also show the annual rainfall anomaly patterns.

The distributions of rainfall anomalies for the period February to May (FMAM) during the first year of the El Niño episodes of 1982-83, 1986-87, and 1997-98 are shown in Fig. 5. Note the large variations in the anomaly patterns among the three episodes. For example, one sees that the anomalies over the Philippines for the 1982-83 El Niño are practically negligible. In contrast, there are strong negative anomalies for the 1997-98 El Niño over almost all parts of the Philippines. The center of the pattern of negative anomalies is located east of the Visayas. These anomalies imply drought conditions over the eastern Visayas and Mindanao. The pattern of anomalies for the 1986-87 episode indicates drought conditions over Northeastern Luzon.

Looking next at the anomaly patterns for the subsequent period of June to September (JJAS) in Fig.6, one sees that the droughts continued over the Philippines during the El Niño episode of 1997-98. The center of the negative anomaly pattern moved to a new location just south of Mindanao. In sharp contrast, positive anomalies developed over most parts of the Philippines, especially over Central Luzon (1982-83 episode) and Central Visayas (1986-87 episode).

The anomalies for the next period, October to January (ONDJ), are shown in Fig. 7. Note that the drought condition for the 1997-98 episode over the Philippines continued. The patterns for the other two episodes are somewhat similar. Except for the northern part of Luzon, both patterns indicate weak to mild drought conditions over the rest of the Philippines. Finally, as a summary, we present the annual anomaly map for the first years of the three episodes in Fig. 8. The map for the 1997-98 episode shows drought conditions for the entire country. The pattern is consistent with the drought conditions shown in Figs. 5 to 7 and is in fair agreement with the composite pattern in Fig.1. The most intense droughts occurred just south of Mindanao. In the case of the two other episodes, most of the country is characterized by positive rainfall anomalies.

The corresponding patterns of rainfall anomaly for the second year of the episodes are shown in Figs. 9 to 12. These figures show the same large variability in the rainfall patterns which are found during the first year of the episodes. With regard to the variability of the patterns in time for any particular episode, one also sees large variations from one season to the next. This is evident especially in the cases for the 1982-83 and the 1986-87 El Niño episodes. There is less time variation for the 1997-98 episode. This episode is characterized by a generally persistent drought condition over the southern part of the Philippines during the entire two-year period.

We summarize the results of the above analysis of the rainfall anomalies by saying that there are large variations in the patterns between different episodes. The largest difference in the patterns is found between the 1997-98 episode and any one of the two other episodes. There are two implications of this result. First, there are variables, other than the Central Pacific SST, which are important in controlling the occurrence of droughts in the Philippines. Second, it is difficult to predict the occurrence of El Niño droughts in the Philippines entirely on the basis of extrapolations from past El Niño episodes.

Relationships between rain gauge observations and SST data

We extend the above analysis of the relationships between SST and rainfall over relatively large regions to an analysis of the relationships between SST and rainfall at individual rain gauge stations. The analysis is done by looking at correlation coefficients between rainfall observed at synoptic stations and the SST anomalies based on Table 1. In computing the coefficients, we use standardized rainfall anomalies.

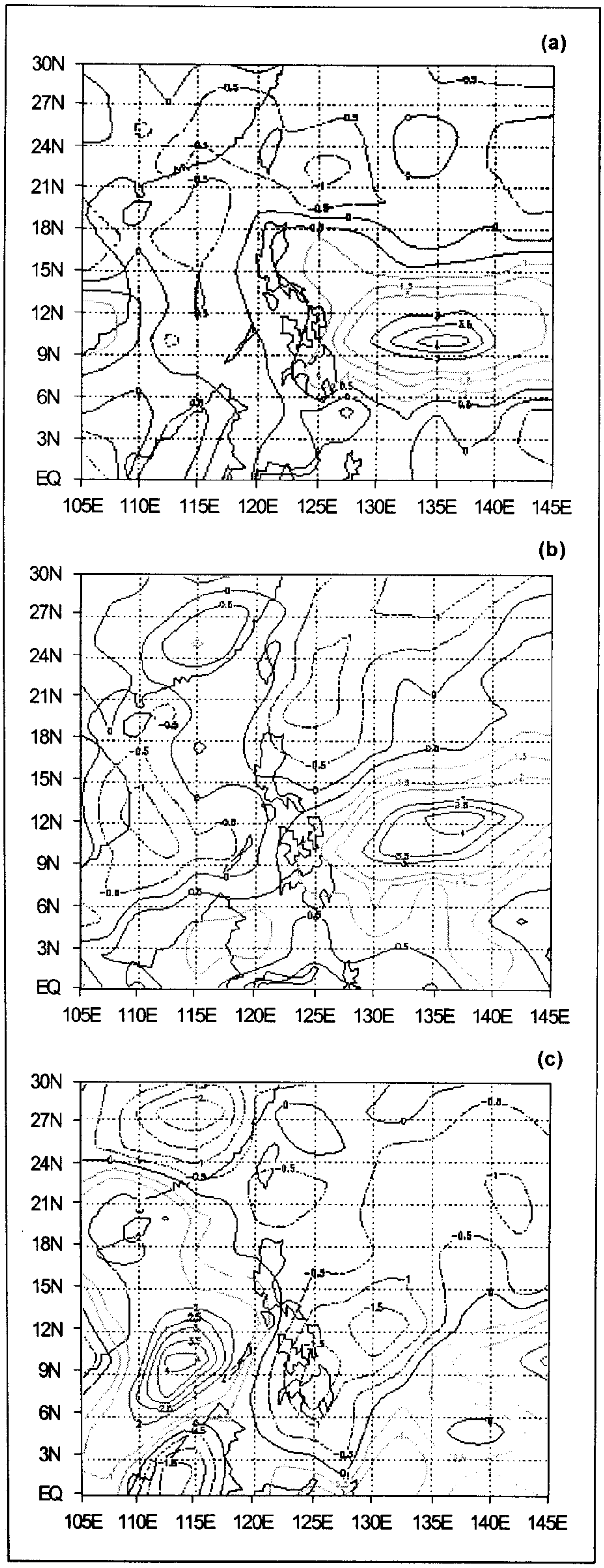

Fig. 5. Rainfall anomaly patterns for the four-month period (February to May) of the first year associated with the three El Niño episodes: (a) 1982-1983; (b) 1986-1987; and (c) 1997-1998.

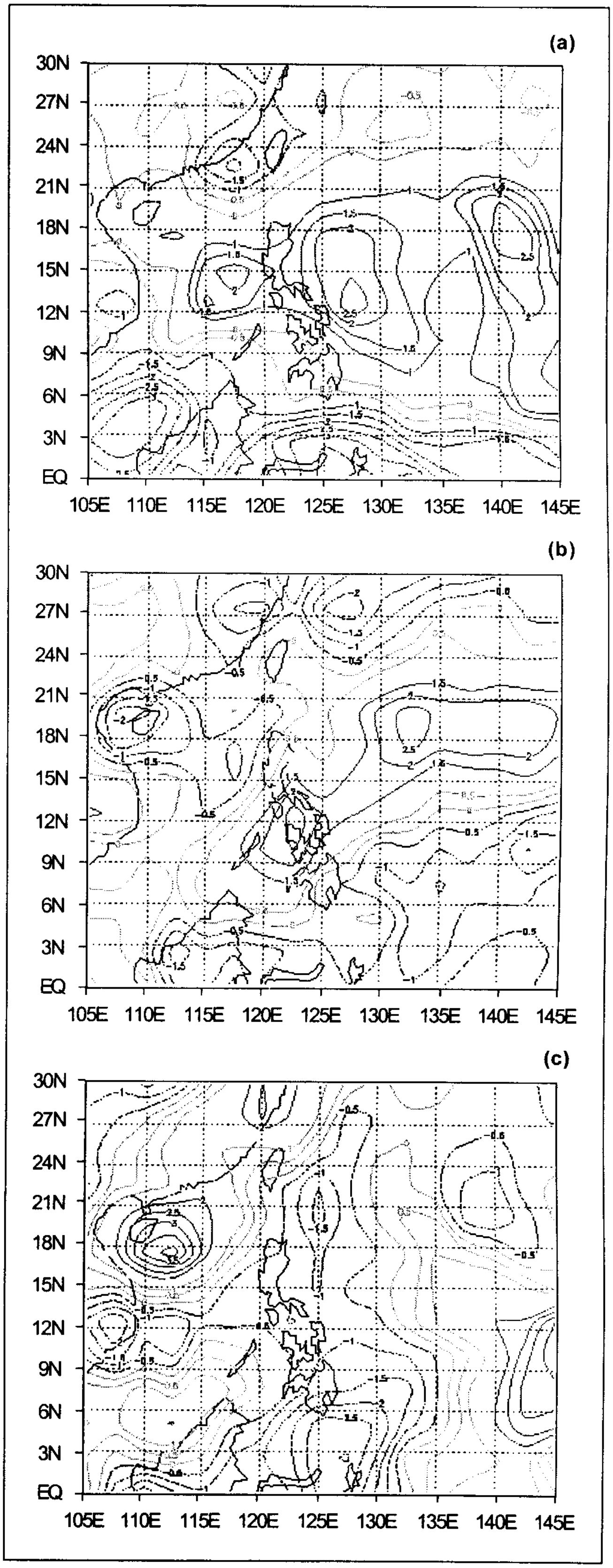

Fig. 6. Rainfall anomaly patterns for the four-month period (June to September) of the first year associated with the three El Niño episodes: (a) 1982-1983; (b) 1986-1987; and (c) 1997-1998.

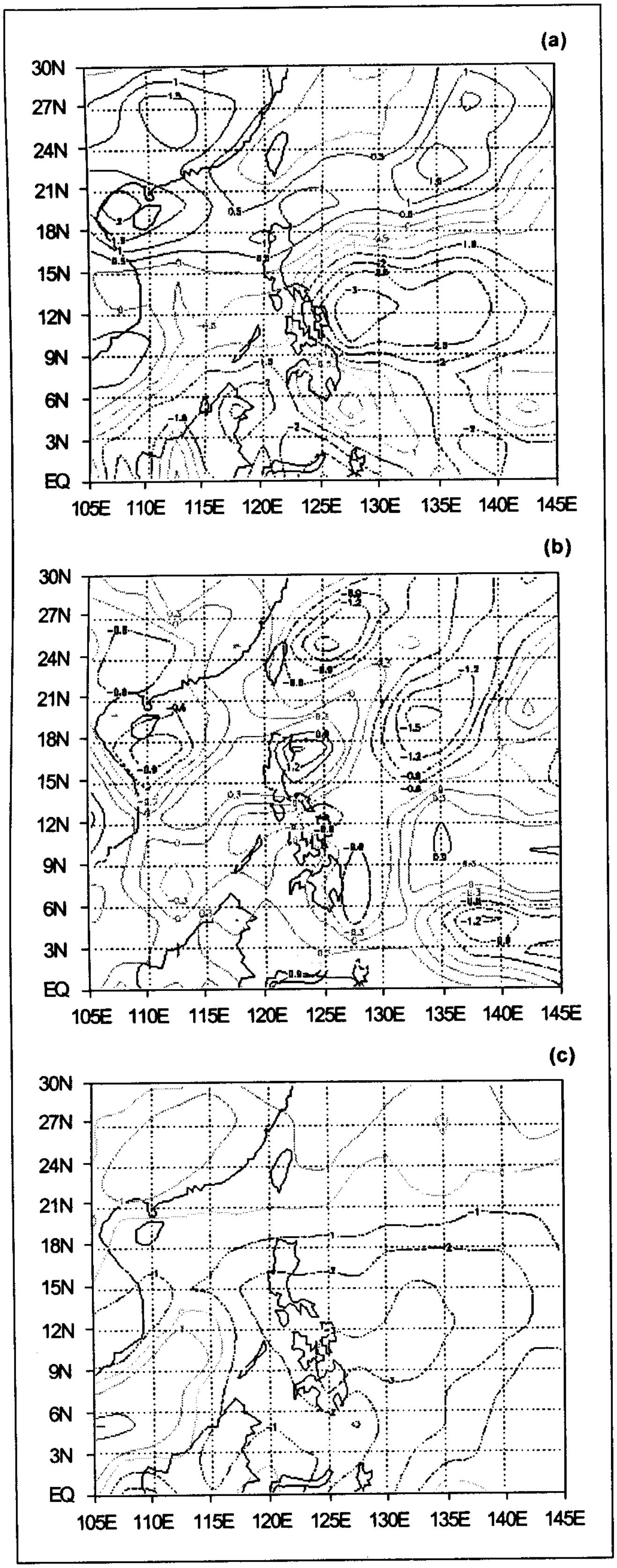

Fig. 7. Rainfall anomaly patterns for the four-month period (October to January) of the first year associated with the three El Niño episodes: (a) 1982-1983; (b) 1986-1987; and (c) 1997-1998.

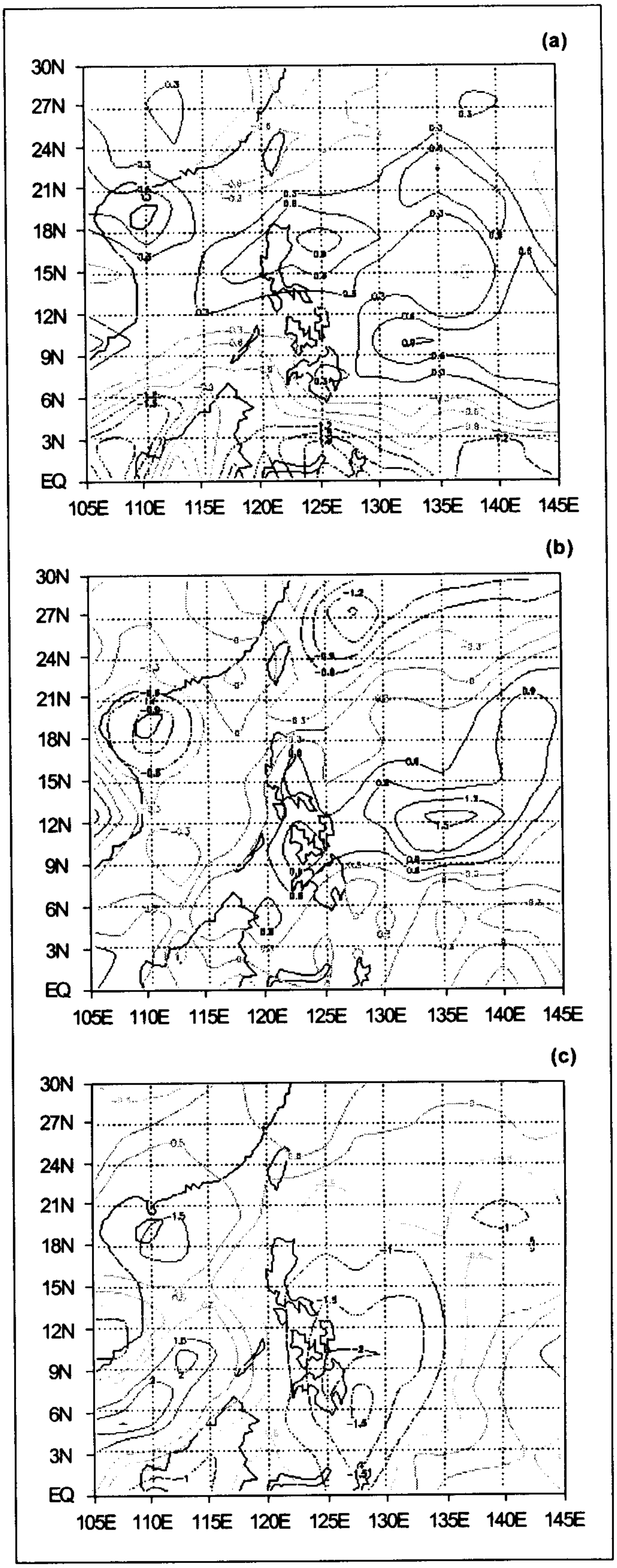

Fig. 8. Rainfall anomaly patterns for the entire first year of the three El Niño episodes: (a) 1982-1983; (b) 1986-1987; and (c) 1997-1998.

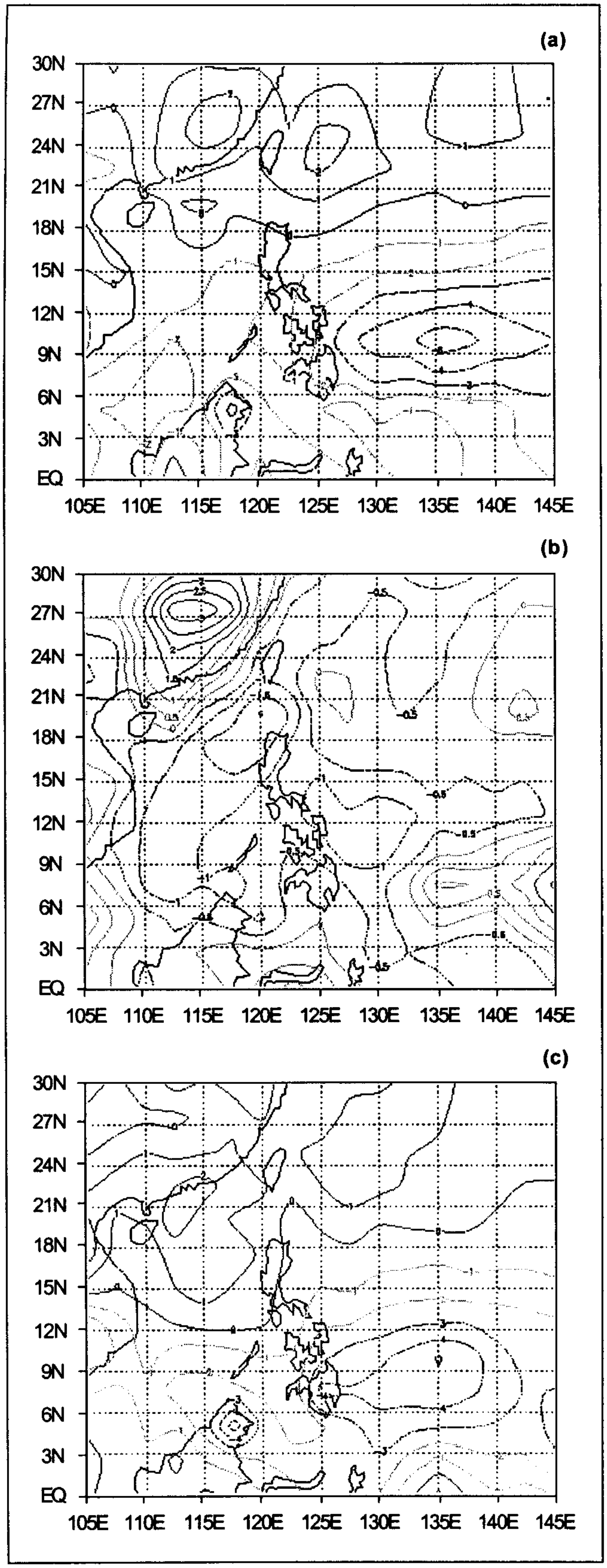

Fig. 9. Rainfall anomaly patterns for the four-month period (February to May) of the second year associated with the three El Niño episodes: (a) 1982-1983; (b) 1986-1987; and (c) 1997-1998.

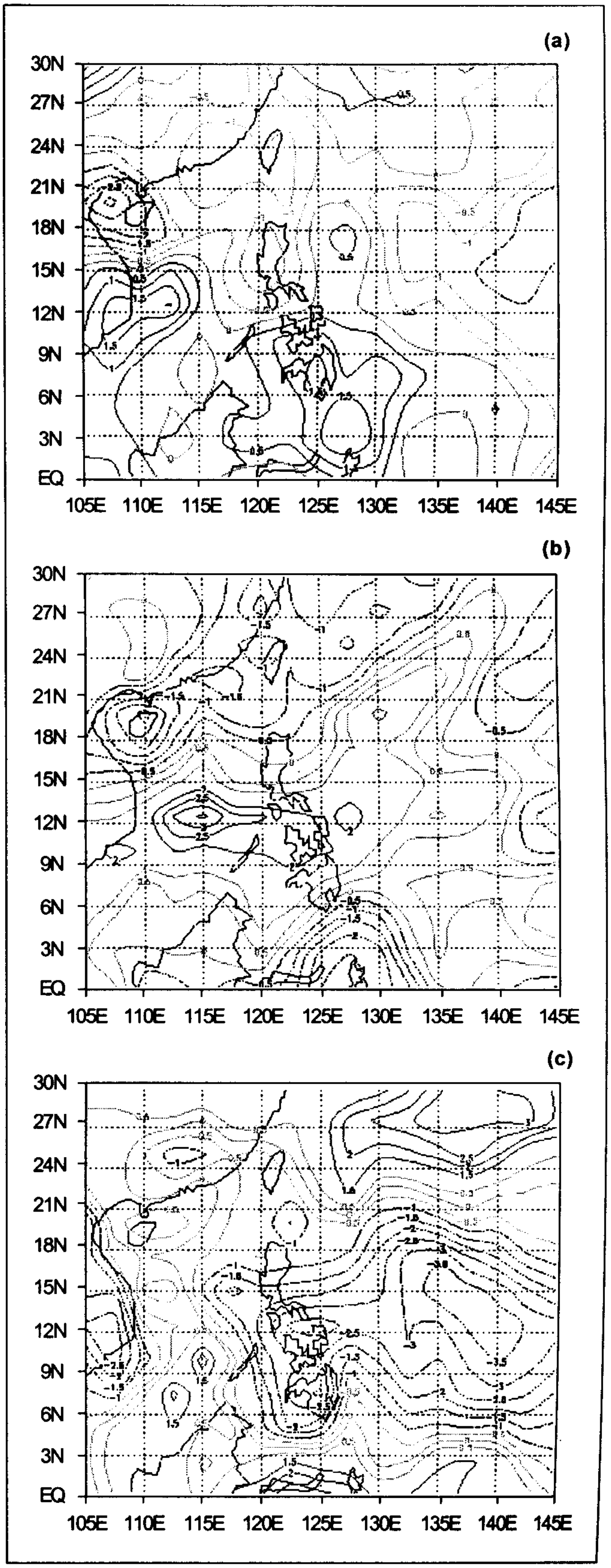

Fig. 10. Rainfall anomaly patterns for the four-month period (June to September) of the second year associated with the three El Niño episodes: (a) 1982-1983; (b) 1986-1987; and (c) 1997-1998.

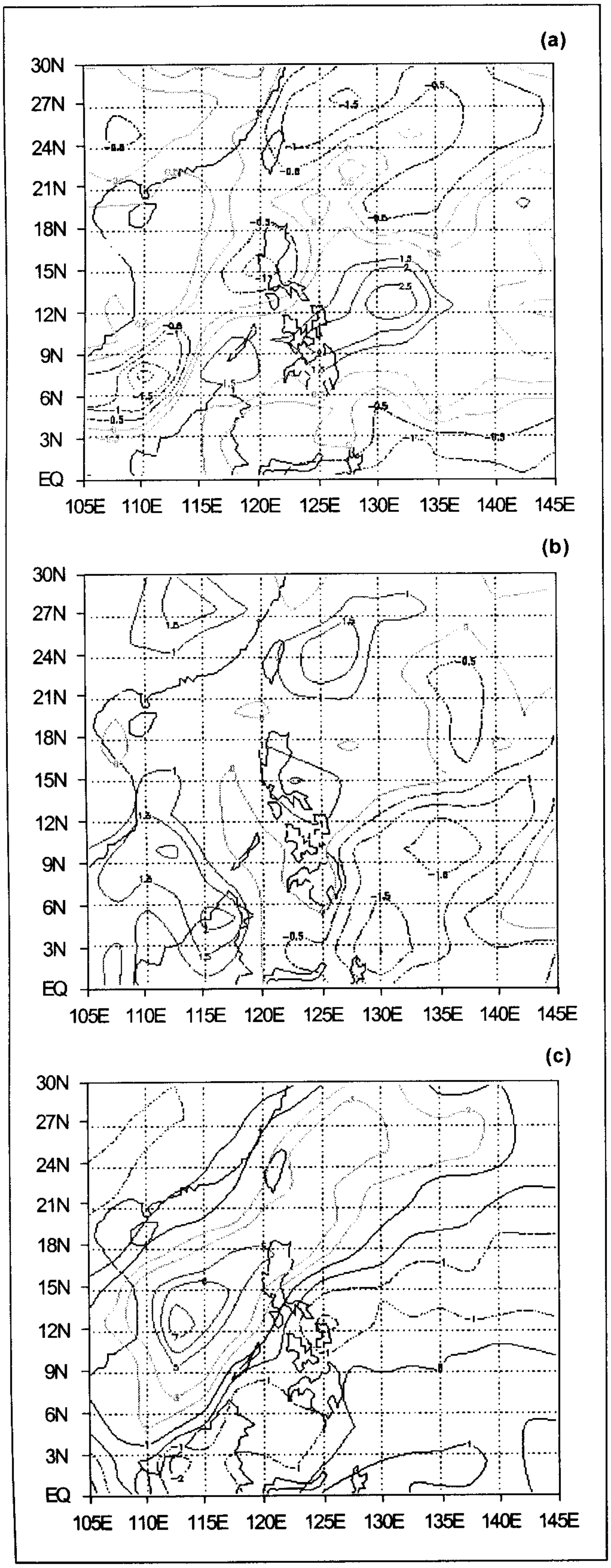

Fig. 11. Rainfall anomaly patterns for the four-month period (October to January) of the second year associated with the three El Niño episodes: (a) 1982-1983; (b) 1986-1987; and (c) 1997-1998.

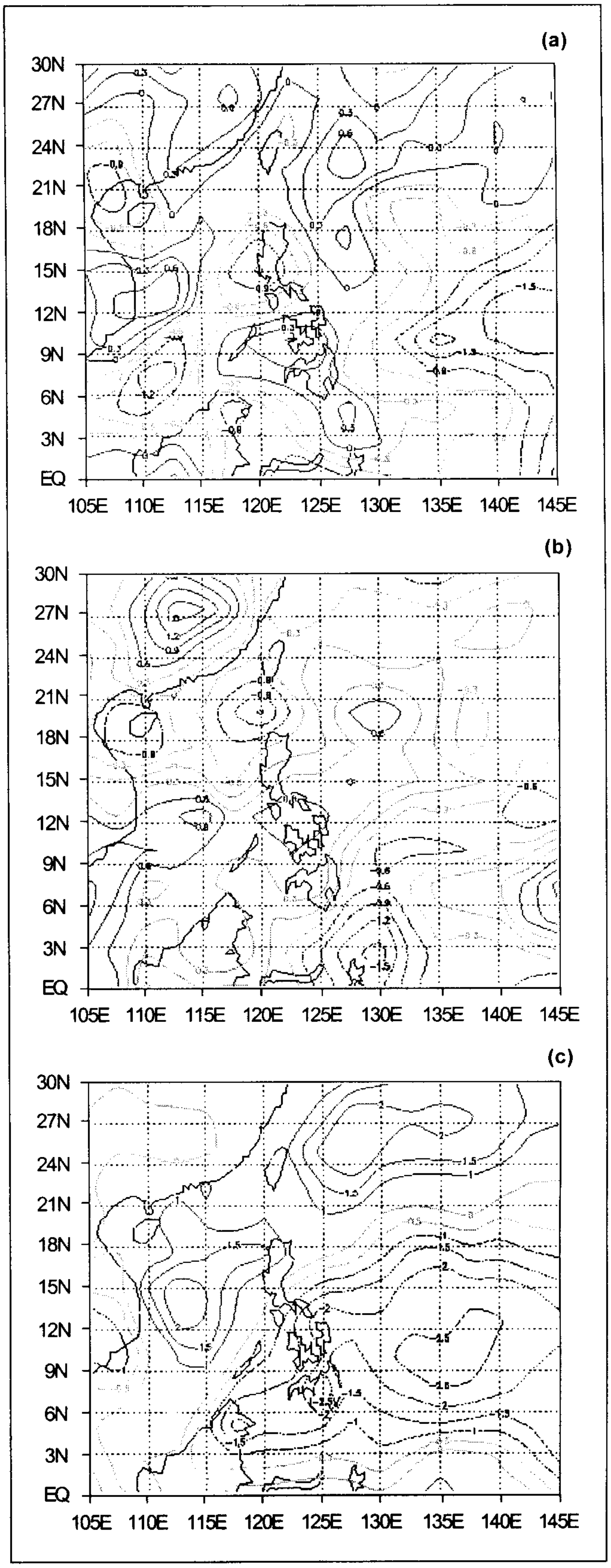

Fig. 12. Rainfall anomaly patterns for the entire second year of the three El Niño episodes: (a) 1982-1983; (b) 1986-1987; and (c) 1997-1998.

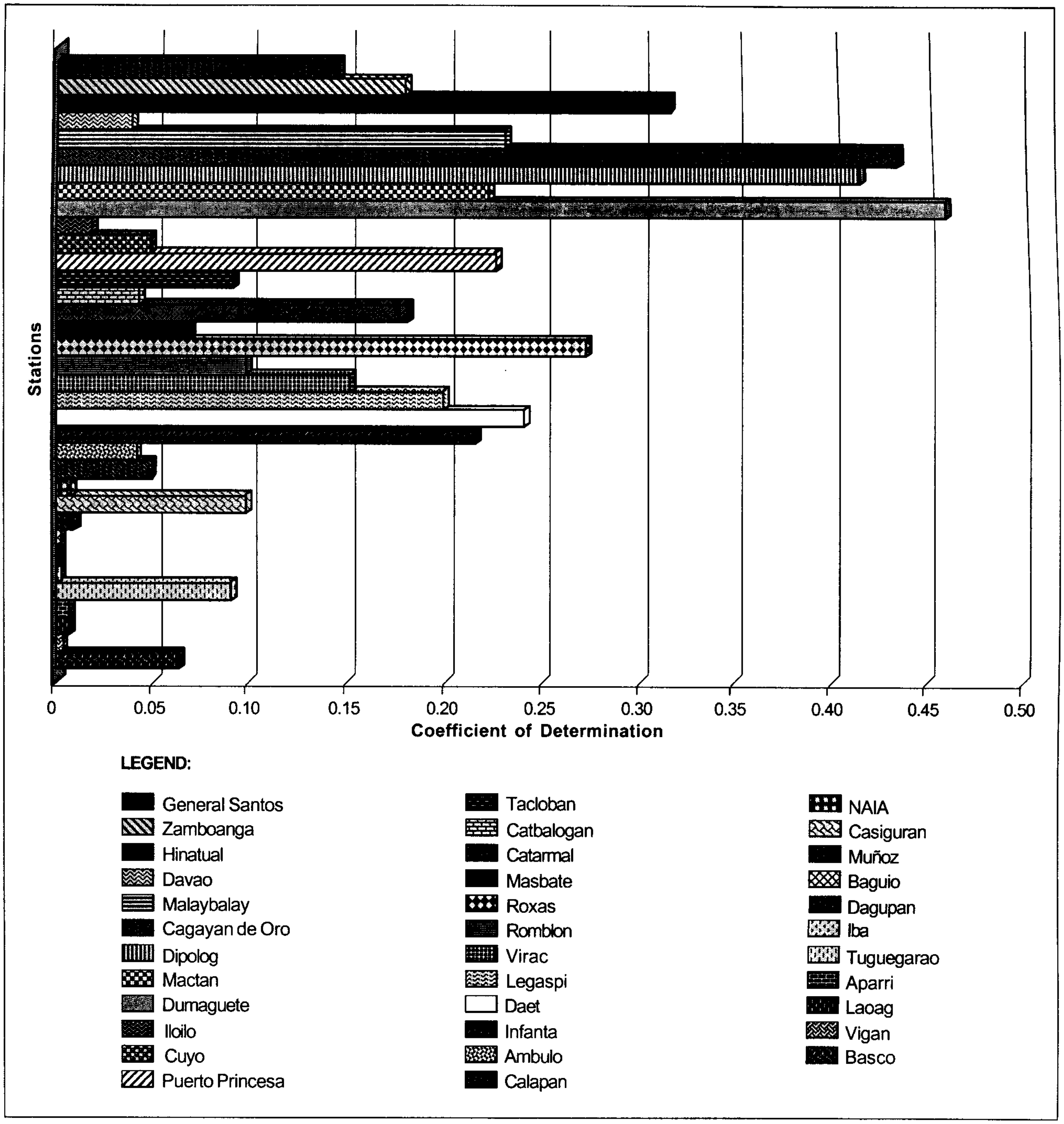

Fig. 13. Coefficient of determination between simultaneous values of the yearly rainfall anomalies (standardized) and the SST index.

Standardized anomalies are specified to be equal to the actual rainfall anomalies divided by their respective standard deviations. In addition, the SST anomaly is expressed in terms of SST index. This index is defined as the algebraic sum of the SST anomalies for the period being considered. For example, the annual SST index is the algebraic sum of the four SST values corresponding to the four quarters of the year in Table 1. The index is, therefore, equivalent to four times the average SST for the period. Correlations between simultaneous values of observed quantities, as well as non-simultaneous (lagged) values, are computed. In the

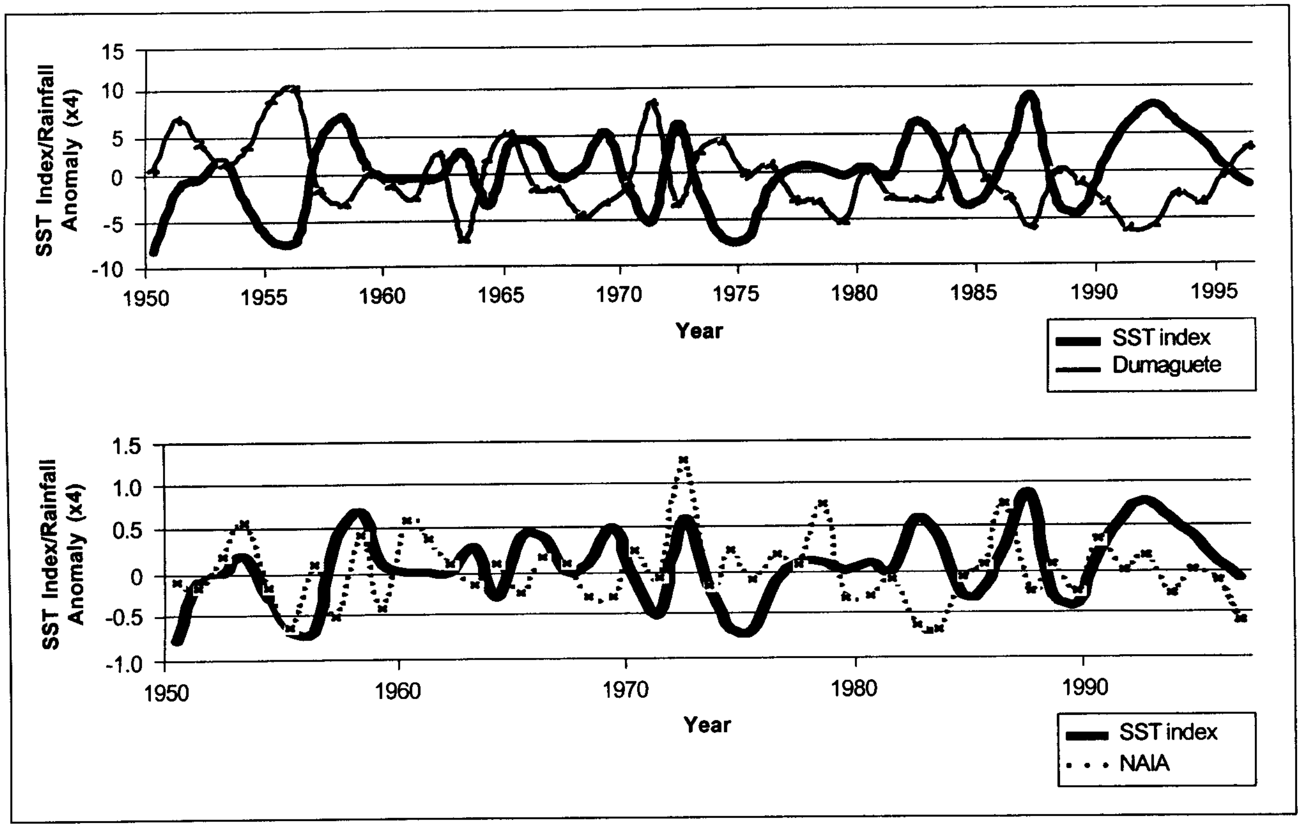

Fig. 14. Time series for the annual SST anomalies and the rainfall anomalies for Dumaguete and Ninoy Aquino International Airport (NAIA).

case of non-simultaneous or lagged correlations, the value of the SST Index precedes that of the rainfall anomaly. Correlation coefficients are computed for the period 1950 to 1996. The results are then expressed in terms of the coefficient of determination (square of the correlation coefficient). The coefficient of determination represents the percentage of the variations in rainfall, which are explained by the corresponding variations in SST.

We begin discussing the results by looking at Fig. 13. This shows the coefficients of determination between the annual rainfall anomaly and the annual SST index for the different stations in the Philippines. One sees that there are high coefficients at certain stations in Western Visayas and in Northern Mindanao. The lowest values are found in Northwestern and Central Luzon. The station in Dumaguete has the highest coefficient of determination with a value of about 46%. This means that 46% of the rainfall anomaly variations for this station are explained by SST variations. The rest of the rainfall variations are explained by other factors. Note the surprisingly low coefficient for Davao in relation to those of other stations in Mindanao. Extremely low coefficients of determination are found for the stations of NAIA (Ninoy Aquino International Airport, Manila), Dagupan, and Iba. The high coefficient of determination for Dumaguete and the low coefficient for NAIA are evident in Fig. 14, which shows the time series for rainfall and SST anomalies for both stations. Looking at the variations of rainfall and SST anomalies for Dumaguete, one sees that positive temperature anomalies generally correspond to negative rainfall anomalies and vice versa. This is not the case for the lower plot of NAIA; there is little correspondence between these two anomalies.

The above correlation analysis considers simultaneous values of SST and rainfall anomalies. From the point of view of prediction, we need to correlate the SST index during a particular time period with the rainfall anomalies for a later period. In this connection, we have computed

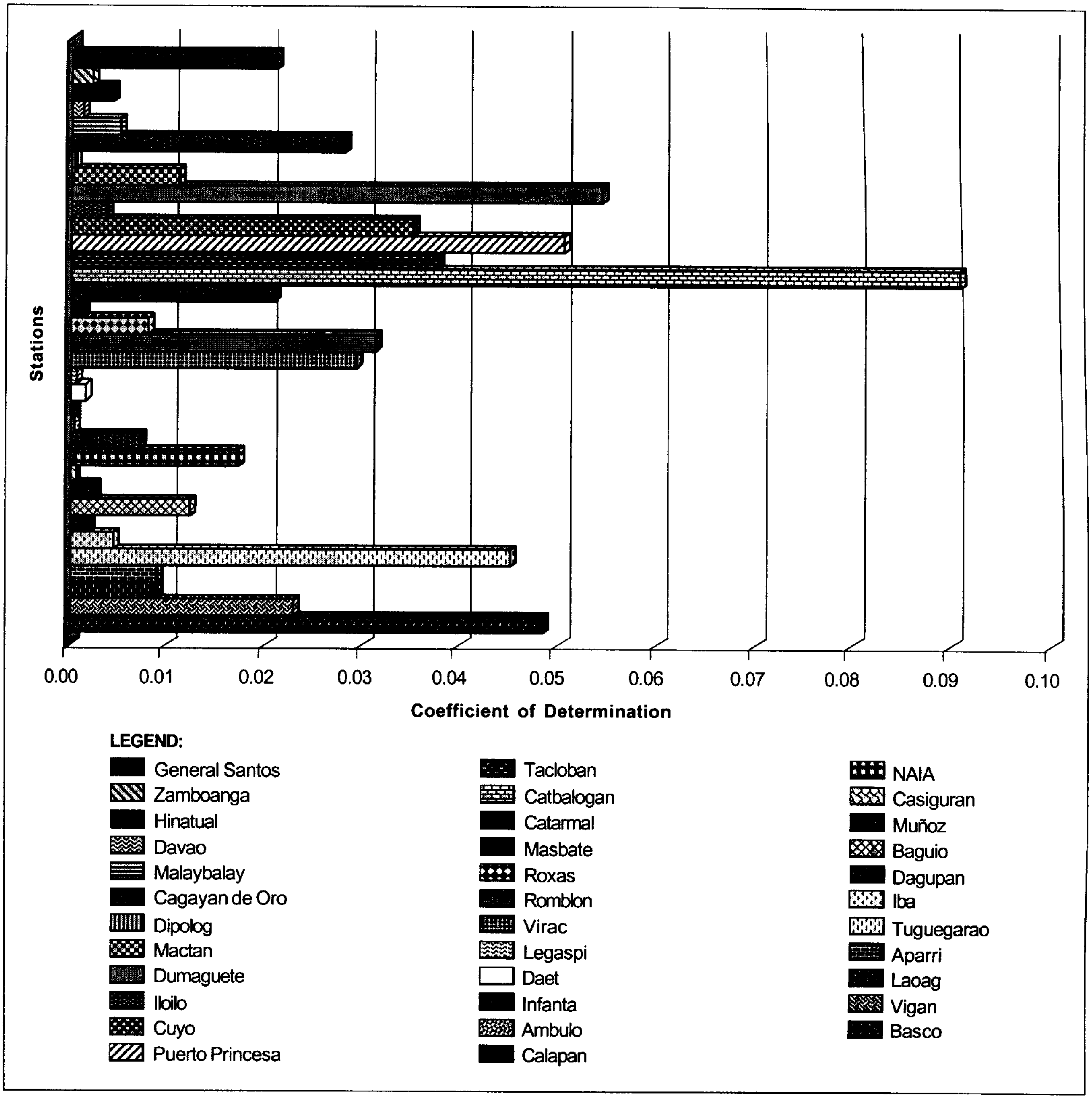

Fig. 15. Coefficients of determination between values of the JJAS rainfall anomalies and the preceding JFMAMJ SST index.

the correlation coefficients between the SST Index corresponding to the period of January to June and the rainfall anomalies for the succeeding period of June to September (JJAS). The correlation computation is repeated with the same SST index and the rainfall anomalies for October to January (ONDJ). Note that in general, these periods (JJAS and ONDJ) are the rainy seasons for the western and eastern sections of the country, respectively. The resulting coefficients of determination are shown in Figs. 15 and 16. The values are very low. The maximum coefficient of determination for JJAS for the entire country, which is only 0.09, belongs to Catbalogan. In the case of the period of ONDJ, the maximum coefficient is a little better at 0.19

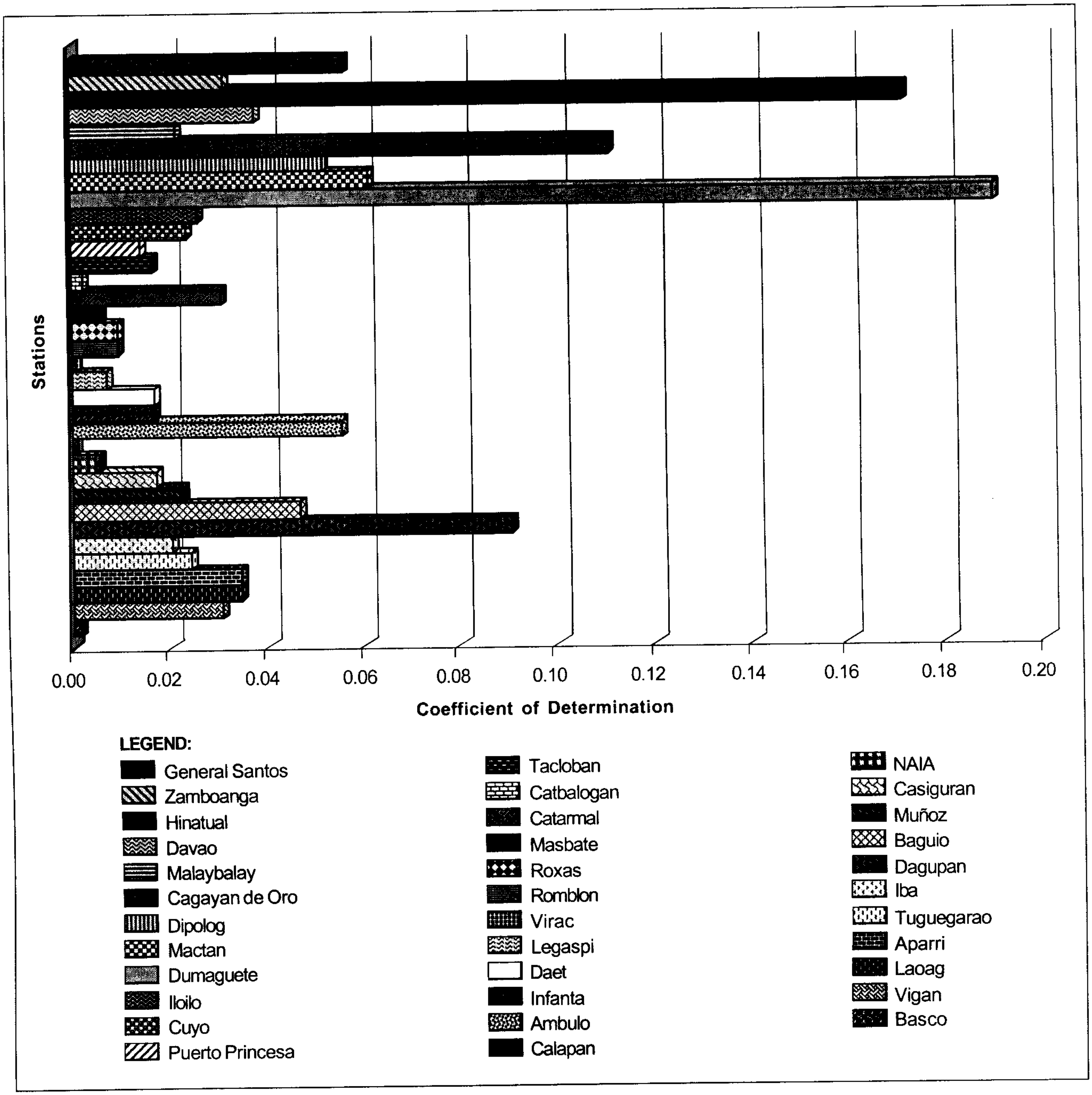

Fig. 16. Coefficients of determination between values of the ONDJ rainfall anomalies and the preceding JFMAMJ SST index.

for Dumaguete. This means that only 19% of the rainfall anomaly variation for the period October to January, is explained by the corresponding variations in the SST anomalies during the preceding six-month period of January to June. The low coefficients indicate that the seasonal prediction of rainfall with SST as a predictor may not be possible.

Regression equations between rainfall and SST anomalies

In spite of the low correlations found above, we persisted in our examination of the predictability problem by developing regression equations involving rainfall anomalies (as predictands) from SST anomalies (as

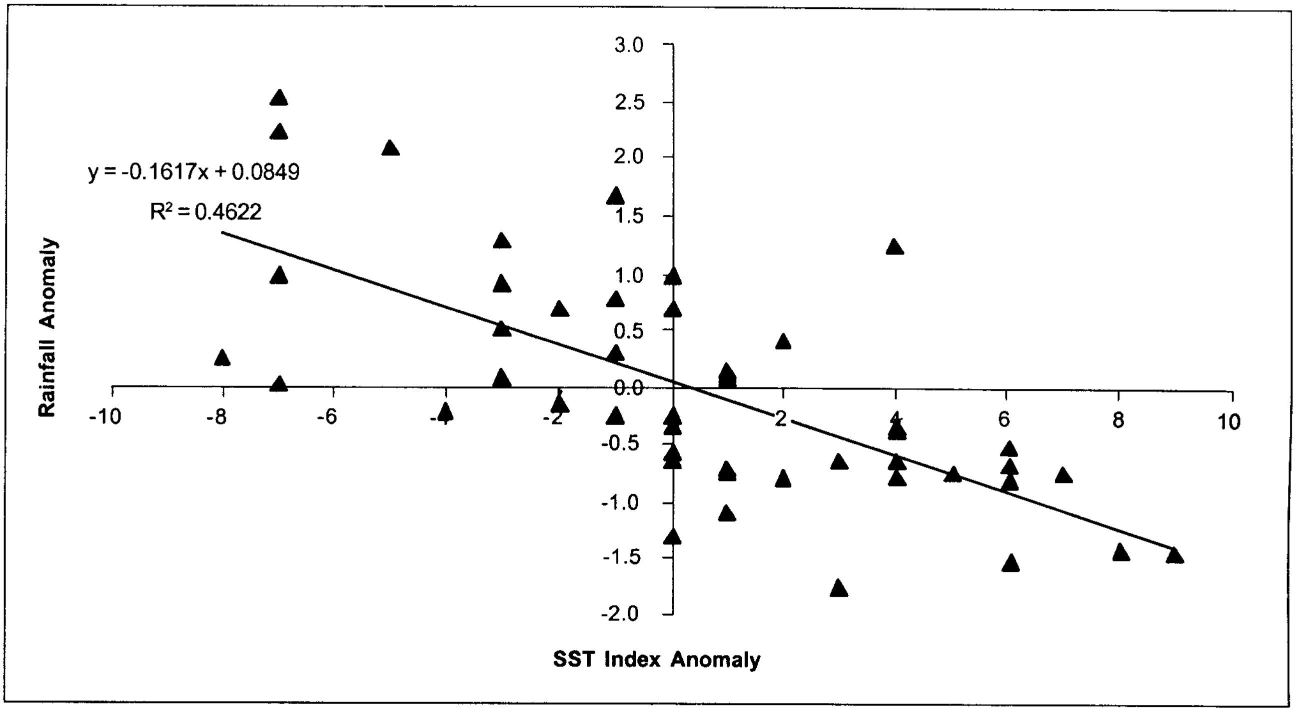

Fig. 17. Scatter diagram between simultaneous values of annual rainfall anomaly and the SST index for Dumaguete, the linear regression equation, and the coefficient of determination.

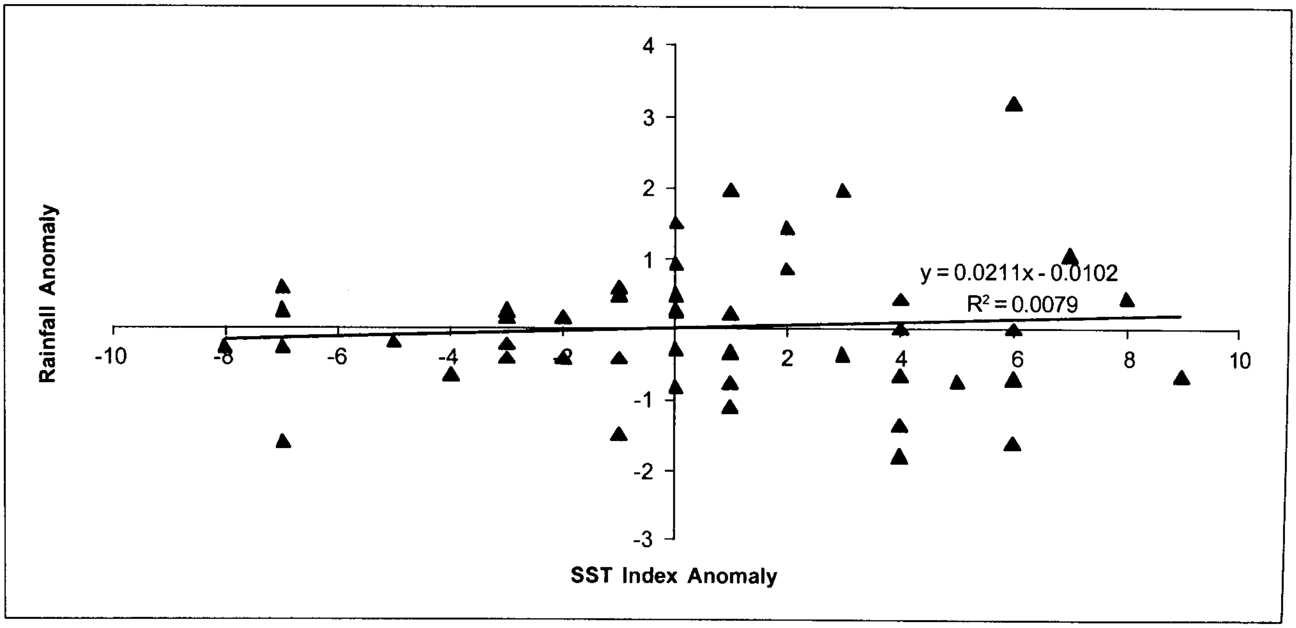

Fig. 18. Scatter diagram between simultaneous values of annual rainfall anomaly and SST index for Ninoy Aquino International Airport (NAIA), the linear regression equation, and the coefficient of determination.

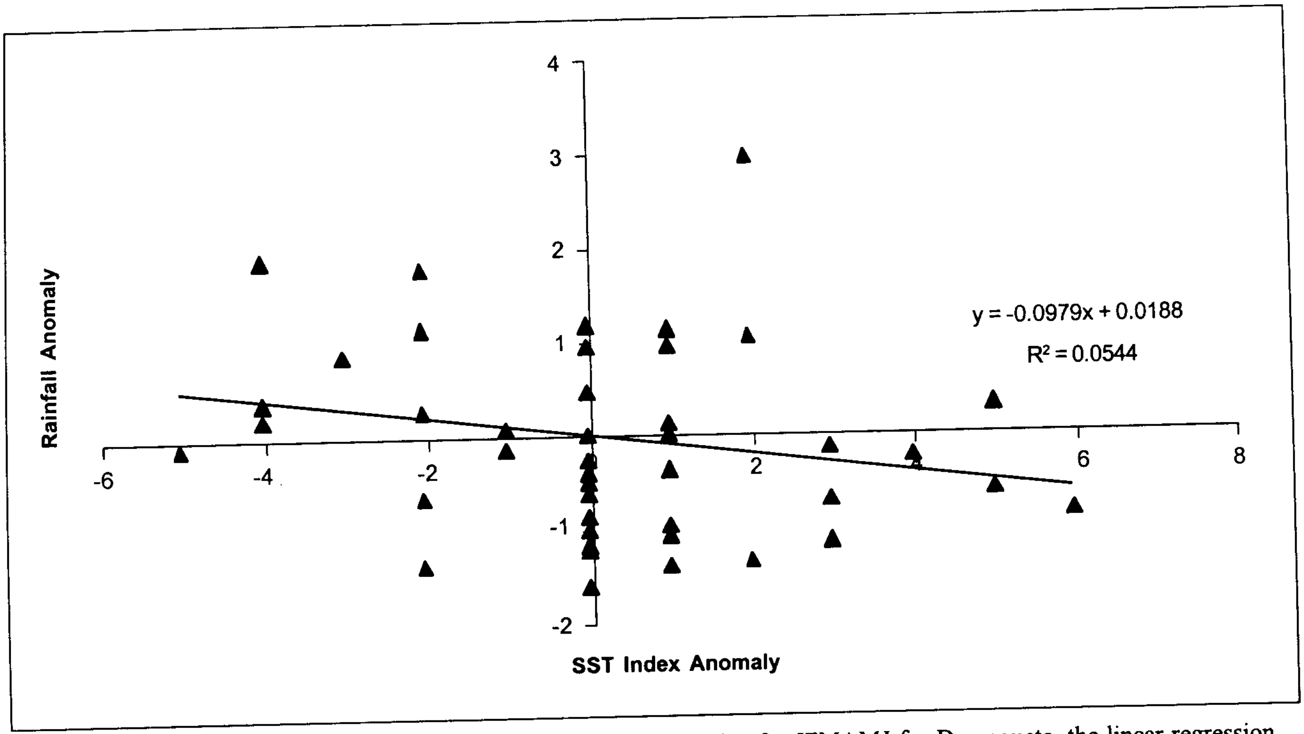

Fig. 19. Scatter diagram between JJAS rainfall anomaly and SST index for JFMAMJ for Dumaguete, the linear regression equation, and the coefficient of determination.

predictors). Equations are derived for the two synoptic stations of Dumaguete and NAIA. Recall that Dumaguete has a high coefficient of determination. Among the many stations with very low coefficients, NAIA has been chosen because it represents the capital city of the Philippines. We discuss first the regression equation for predicting the annual rainfall anomaly from the corresponding SST anomaly. Here, the values of rainfall and SST are for the same period of time, i.e., simultaneous values. The regression equation for predicting the annual rainfall anomaly for Dumaguete is:

$$Y = -0.1617X + 0.0849 \qquad (1)$$

The corresponding regression line is plotted in the scatter diagram (Fig. 17). The scatter of individual points away from the regression line is not excessive and is consistent with a correlation coefficient of 0.7. Note that in general, the regression line predicts negative rainfall anomalies if SST anomalies are positive (El Niño conditions). Moreover, the line indicates that La Niña conditions are generally characterized by positive rainfall anomalies. The regression line for predicting the annual rainfall anomaly at NAIA is:

$$Y = 0.0211X - 0.0102 \qquad (2)$$

The corresponding scatter diagram is shown in Fig. 18. Note that the scatter is very large. Moreover, the orientation of the regression line is incorrect. It indicates that droughts occur during periods of negative SST anomaly and vice versa. It also indicates that the regression equation is practically useless for the prediction in NAIA.

Next, we consider the possibility of using the January to June SST index as a predictor for seasonal rainfall during the period June to September. The regression equation for predicting the JJAS for Dumaguete is:

$$Y = -0.0979X + 0.0188 \qquad (3)$$

The scatter diagram is shown in Fig. 19. The scatter is large. However, the orientation of the regression line

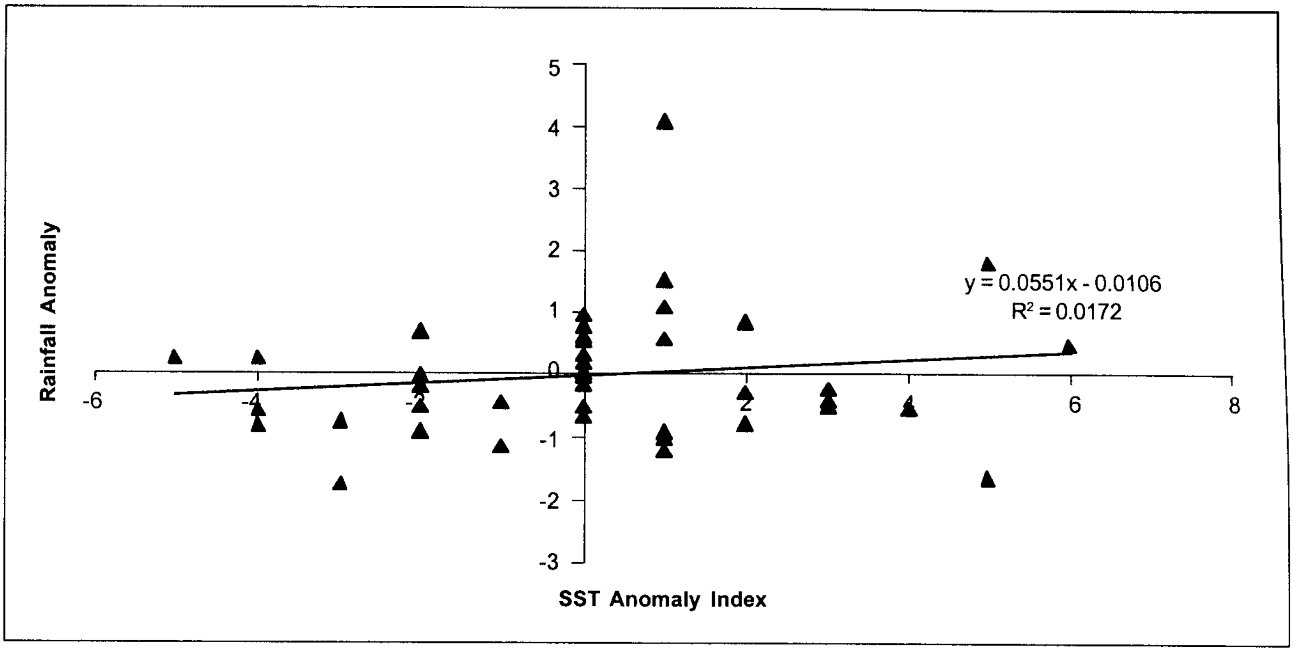

Fig. 20. Scatter diagram between JJAS rainfall anomaly and SST index for JFMAMJ for Ninoy Aquino International Airport (NAIA), the linear regression equation, and the coefficient of determination.

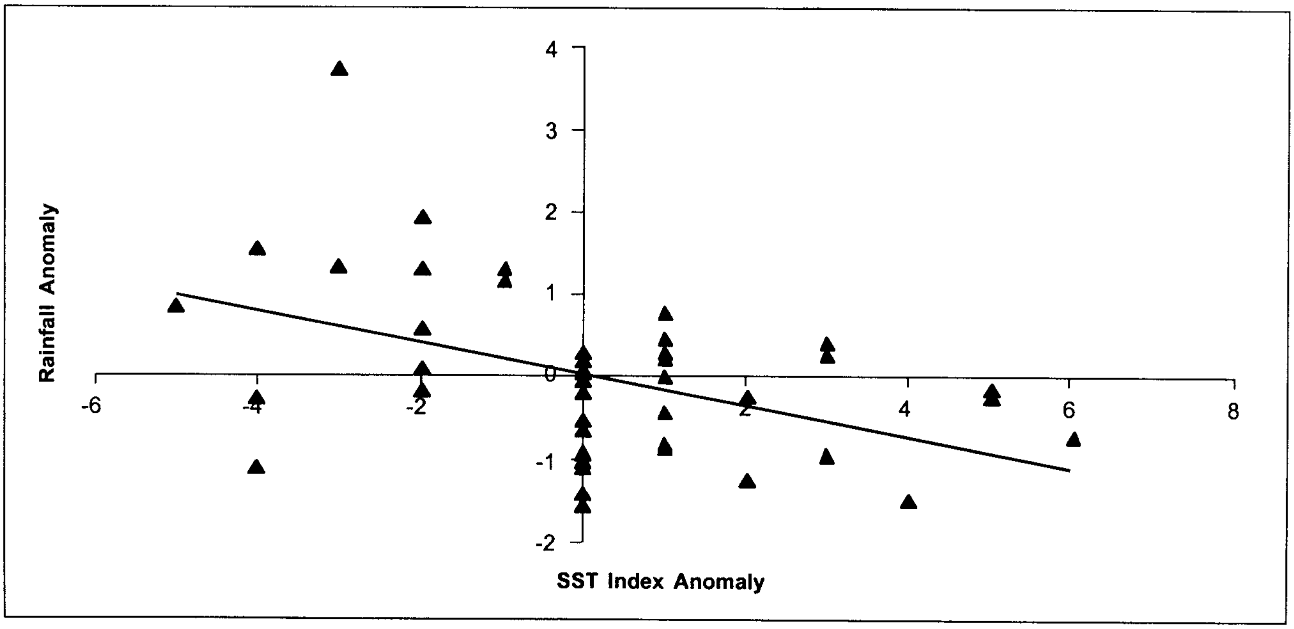

Fig. 21. Scatter diagram between ONDJ rainfall anomaly and SST index for JFMAMJ for Dumaguete, the linear regression equation, and the coefficient of determination.

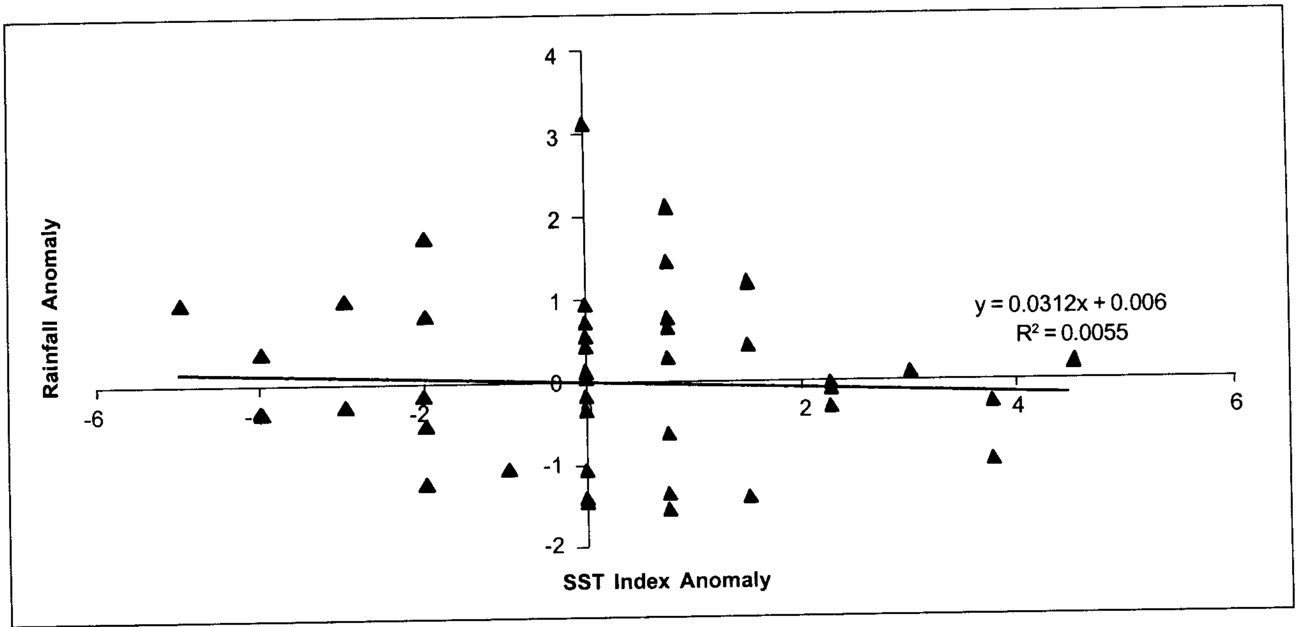

Fig. 22. Scatter diagram between ONDJ rainfall anomaly and SST index for JFMAMJ for Ninoy Aquino International Airport (NAIA), the linear regression equation, and the coefficient of determination.

correctly indicates droughts during El Niño episodes and floods during La Niña episodes. The corresponding regression equation for the same predictor and predictand for NAIA is:

$$Y = 0.0551X - 0.0106 \quad (4)$$

The scatter diagram is shown in Fig. 20. Again, as in the case of the annual scatter diagram for NAIA in Fig. 18, the scatter is equally large.

Next, we consider the prediction of the October to January rainfall anomaly using the same SST predictor. The regression equation for Dumaguete is:

$$Y = -0.1825X + 0.0348 \quad (5)$$

The scatter diagram for Dumaguete is shown in Fig. 21. The scatter is large but it is not as large as the case for predicting the JJAS rainfall in Fig. 19. The regression equation for predicting the NAIA rainfall anomaly for the season ONDJ is:

$$Y = -0.0312X + 0.006 \quad (6)$$

The scatter diagram is shown in Fig. 22. The scatter is somewhat less than that of Fig. 20 for the corresponding prediction of the JJAS rainfall anomaly, but it is still large.

Evaluation of the regression equations for prediction

Next, we consider the evaluation of the regression equations for predicting rainfall anomalies for the following periods: annual or yearly, June to September, and October to January. The predictor for the annual rainfall anomaly is the annual SST index. On the other hand, the predictor for the rainfall anomaly during the other two periods is the SST index for the period January to June. The first step in the application of the regression equations is to substitute the appropriate predictors in the equations in order to predict the rainfall anomaly. There is a prediction for three rainfall anomalies for each year of the period, 1950 to 1996. The three predictions correspond to the annual rainfall anomaly, the JJAS rainfall anomaly, and the ONDJ rainfall anomaly. There is also an observed anomaly associated with each predicted anomaly. There are forty-seven cases of observed, as well as, predicted values. Each case corresponds to each year of the period 1950 to 1996.

Table 2. The contingency table for the annual rainfall anomaly prediction. The predictor is the contemporary annual SST index.

DUMAGUETE

		OBSERVED			
		Drought	**Normal**	**Flood**	**Total**
PREDICTED	**Drought**	14 64%	0	1	15
	Normal	0	5 56%	6	11
	Flood	8	4	9 56%	21
	Total	22	9	16	47

NAIA

		OBSERVED			
		Drought	**Normal**	**Flood**	**Total**
PREDICTED	**Drought**	0	0	0	0
	Normal	20	12 100%	15	47
	Flood	0	0	0	0
	Total	20	12	15	47

Table 3. The contingency table for the June to September rainfall anomaly prediction. The predictor is the preceeding January to June SST index.

DUMAGUETE

		OBSERVED			
		Drought	**Normal**	**Flood**	**Total**
PREDICTED	**Drought**	4 20%	2	1	7
	Normal	16	6 30%	12	34
	Flood	0	2	4 24%	6
	Total	20	10	17	47

NAIA

		OBSERVED			
		Drought	**Normal**	**Flood**	**Total**
PREDICTED	**Drought**	0	0	1	1
	Normal	20	7 100%	16	43
	Flood	1	0	2 11%	3
	Total	21	7	19	47

For simplicity in the evaluation, we have introduced three categories of rainfall anomalies: drought, normal, and flood. These are defined as follows:

Drought: Rainfall Anomaly < -0.25
Normal: $-0.25 \leq$ Rainfall Anomaly ≤ 0.25
Flood: Rainfall Anomaly > 0.25

Using the above definition, we classify each rainfall anomaly into the appropriate category. The verification of the rainfall anomaly predictions against the observed values are done in terms of the above three categories.

The results of the verification are summarized in the form of contingency tables. We now present the contingency tables for the annual forecasts for Dumaguete and NAIA in Table 2. Looking at the contingency table for Dumaguete, one sees that there are a total of 22 cases (or years) of observed drought occurrences. Fourteen cases are predicted correctly; therefore, the accuracy of drought prediction is 64%. One also sees that there are a total of 16 cases of observed flood occurrences. Nine of these are predicted correctly, representing an accuracy of 56%. One interesting feature, which is indicated by the contingency

Table 4. The contingency table for the October to January rainfall anomaly prediction. The predictor is the January to June SST index.

DUMAGUETE

		OBSERVED			
		Drought	**Normal**	**Flood**	**Total**
PREDICTED	**Drought**	4 25%	4	2	10
	Normal	11	9 56%	6	26
	Flood	1	3	7 47%	11
	Total	16	16	15	47

NAIA

		OBSERVED			
		Drought	**Normal**	**Flood**	**Total**
PREDICTED	**Drought**	0	0	0	0
	Normal	19	10 100%	18	47
	Flood	0	0	0	0
	Total	19	10	18	47

Table 5. The contingency table for the annual rainfall anomaly prediction using another definition of the rainfall categories. The predictor is the contemporary annual SST index.

DUMAGUETE

		OBSERVED			
		Drought	**Normal**	**Flood**	**Total**
PREDICTED	**Drought**	9 50%	3	1	13
	Normal	9	9 56%	5	23
	Flood	0	4	7 54%	11
	Total	18	16	13	47

NAIA

		OBSERVED			
		Drought	**Normal**	**Flood**	**Total**
PREDICTED	**Drought**	0	0	0	0
	Normal	14	23 100%	10	47
	Flood	0	0	0	0
	Total	14	23	10	47

table, is the fact that the regression equation predicts eight cases of flood for which drought conditions are observed. Still another is the fact that there are six predicted normal rainfall conditions; however, flood conditions are observed.

Next, we look at the predictions for NAIA. The contingency table shows that the regression equation does not predict any occurrence of either a drought or a flood condition. However, the table shows that there are 20 occurrences of observed drought conditions and 15 occurrences of observed flood conditions, respectively. In other words, the regression equation has no skill in predicting either droughts or floods.

We now look at the predictions of rainfall anomaly for the period, June to September. The contingency table is shown in Table 3. The predictor for these predictions is the SST index for January to June. The accuracies of the predictions for Dumaguete are 20% for drought and 24% for flood. These percentages are much lower than those of the corresponding annual predictions. The corresponding accuracies for the NAIA predictions are 0% for drought and 11% for flood. This accuracy is a very slight improvement of the performance of the regression equation for the annual rainfall prediction.

Finally, we look at the predictions of the rainfall anomaly for the period October to January. The contingency table for this case is shown in Table 4. The table for Dumaguete shows the following accuracy of prediction: drought, 25% and flood, 47%. The percentages are an improvement over those for the June to September predictions. The percentages for NAIA are zero for both flood and drought prediction.

The definition of the limits for the three categories of rainfall anomaly is rather arbitrary. In order to determine the sensitivity of the accuracy of the prediction to the definition, we adopted another definition. This is,

Drought: Rainfall Anomaly < -0.5
Normal: $-0.5 \leq$ Rainfall Anomaly ≤ 0.5
Flood: Rainfall Anomaly > 0.5

With the aid of this new definition, we arrived at the contingency table (Table 5) for the prediction of the annual rainfall anomaly from the annual SST index. This should be compared with the corresponding contingency table (Table 2) made by using the original definition of rainfall categories. Here, the accuracies of the drought and flood predictions are 50% and 54%, respectively. The corresponding percentages with the original category definitions are 64% and 56%, respectively. These differences appear to be insignificant. Therefore, we conclude that the results of our evaluation are not very sensitive to the specification of the rainfall intervals in the categories.

In summary, the results of the regression analysis indicate that the prediction of rainfall anomalies from SST anomalies is difficult. The percentages of accuracy are low, especially for the cases when the antecedent SST anomalies are used to predict occurrence of the rainfall anomalies. In the case of the prediction of annual rainfall, the percentages are much better. However, these percentages are certainly gross overestimates because we use simultaneous values of both SST and rainfall. In other words, this is equivalent to having a perfect forecast of the SST index for use in the regression equation. However, reasonably accurate SST forecasts are currently not available. The inaccuracy

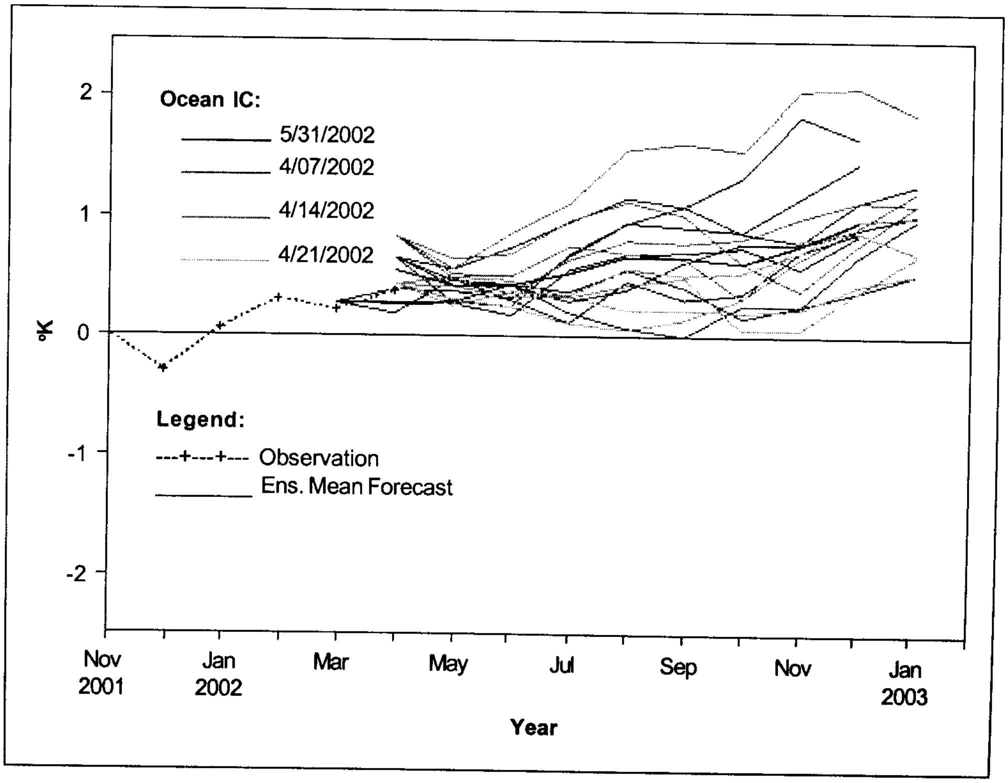

Fig. 23. Predicted and observed sea surface temperature anomalies for the Niño 3.4 region of the Central Pacific from the latest version of the NCEP coupled model. Initial time of forecast is April. The lines correspond to different forecasts which are made by using different initial oceanic and atmospheric initial conditions. The plus sign (+) connected by dashed lines at the beginning of the time series indicate observed monthly anomalies. *Source: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/bulletin/figf4b.gif*

of present forecasts of SST anomalies is indicated in Fig. 23. Note that there is a large scatter among the different forecasts. Another reason for overestimating the accuracy of the rainfall forecasts is the fact that the test of the regression equation is done using the so-called dependent data. These are data which are used in deriving the regression equation. A better test should use independent data.

CONCLUSION

This report describes a study of the predictability of rainfall anomalies due to El Niño and La Niña episodes. The data used are rain gauge observations, NCEP-NCAR Reanalysis rainfall data and sea surface temperatures from the Climate Prediction Center of NOAA. The first part of the study analyzes the regional variability of rainfall anomaly patterns associated with three major El Niño episodes: 1982-83, 1986-87, and 1997-98. The development of rainfall anomaly patterns for three-monthly periods, during the two years of the episodes, is examined. The examination shows large differences in the anomaly patterns between any two episodes. One can conclude from these differences that it is difficult to infer from past rainfall anomaly patterns the corresponding patterns for any particular episode in the future.

The second part deals with the possibility of predicting the occurrence of droughts and floods at rain gauge stations in the Philippines. A general survey of this possibility is done by determining the correlation between the Central Pacific sea surface temperatures and rainfall observations at the stations. The survey shows that, as a whole, the magnitudes of the coefficients of determination are small. The maximum coefficient of determination (0.46) is found for Dumaguete. Very small values of the coefficient are found for stations in Western Luzon. The actual prediction of rainfall for two selected stations, Dumaguete and NAIA (Manila), is investigated with the aid of regression equations. Three cases of predictions are done. In the first case, the predictand is the annual rainfall anomaly at each of the two stations; the predictor is the annual sea surface temperature index. For this case, there is no time lag between the predictor and the predictand. The accuracy of the prediction is analyzed with the aid of contingency tables. The analysis shows that, for the station of Dumaguete, the regression equation is able to predict about 50% of the occurrence of droughts or floods. For the station of NAIA, a similar analysis shows that the regression equation is not able to predict the occurrences of either droughts or floods.

In the second case of prediction, the predictand is the rainfall anomaly for the period June to September. The predictor is the SST index for the previous January to June period. In the case of Dumaguete, the regression equation is able to predict approximately 25% of the occurrences of drought and flood. For NAIA, the regression equation is not able to predict any drought occurrence; however, it predicts 10% of the flood occurrences.

In the third case of prediction, the predictand is the rainfall anomaly for the period October to January. Again the predictor is the SST index for the previous January to June period. For Dumaguete, the regression equation is able to predict 25% of the drought occurrences and 47% of the flood occurrences. In the case of NAIA, the regression equation fails to predict the occurrence of a drought or a flood.

One can conclude from the present study that it is difficult to develop a statistical method for predicting the occurrences of droughts and floods solely from sea surface temperatures over the Central Pacific Ocean. In order to be able to improve the statistical forecasts, one should incorporate other predictors.

REFERENCES

Estoque, M.A., J. Luque, M. Chandek-Monteza, & J. Garcia, 1985. Effects of El Niño on Panama Rainfall. *Geofisica International.* 24: 385-381.

Grimm, A.M., S.E. Ferraz, & J. Gomes, 1998. Precipitation anomalies in Southern Brazil associated with El Niño and La Niña events. *J. Climate.* 11: 2863-2880.

Hoerling, M.P., A. Kumar, & M. Zhong, 1997. El Niño, La Niña, and the non-linearity of their teleconnection. *J. Climate.* 10: 1769-1786.

Kistler, R., et al., 2001. The NCEP-NCAR 50-Year reanalysis: Monthly means CD-ROM and documentation. *Bull. Amer. Meteor. Soc.* 82: 247-267.

Montecino, A., A. Diaz, & P. Aceituno, 2000. Seasonal diagnostic and predictability of rainfall in sub-tropical South America based on Pacific SST. *J. Climate.* 13: 746-758.

Ropelewski, C.F., & M.S. Halpert, 1987. Global and regional scale precipitation patterns associated with El Niño-Southern Oscillation. *Mon. Wea. Rev.* 115: 1606-1626.

Schonher, T., & S.E. Nicholson, 1989. The relationship between California rainfall and ENSO events. *J. Climate.* 2: 1258-1269.

Uvo, C. B., C. A. Repelli, S. E. Zebiak, & Y. Kushnir, 1998. The relationships between tropical Pacific and Atlantic SST and northeast Brazil monthly precipitation. *J. Climate.* 11: 551-562.