A Study of Rainfall Variations in the Philippines: 1950-1996[1]

Bonifacio G. Pajuelas
Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA)
Weather and Flood Forecasting Center (WFFC),
Agham Road, East Triangle, Diliman, Quezon City 1101 Philippines
Tel. No.: 434-8080, Telefax: 929-4865, E-mail: odstaff@pacific.net.ph

ABSTRACT

The long-period rainfall variations in the Philippines are studied using unfiltered and filtered Rainfall Anomaly Index (RAI). To have RAI's that are representative for each group, zones of quasi-homogeneous climate were constructed based on highly correlated stations ($r > 0.75$), narrow standard deviation, and period of maximum rainfall using the 1950-1996 monthly rainfall total.

Variance analyses of the RAI's suggest that unfiltered samples do not significantly differ from the normal distribution except for the western part (climate type 1) that have significant positive skewness and peakedness. The RAI's contain a significant amount of non-random elements and a significant negative change in mean is reflected over the central Visayas and Mindanao (climate type 3). Filtered RAI's that are not significantly different from the normal distribution (at least for χ^2 test) indicated significant trend over areas with high-variable rainfall (i.e., climate types 1, 2, 4 & 5).

In general, long-period rainfall may have changed over the period of study. The 10-year filtered RAI's have the possibility of falling rate over climate types 1, 2 & 5, but increasing rate over climate type 4. These trends are indicated towards the rainfall-sensitive months (i.e., February through May) during El Niño or La Niña events. Falling rate is also significant from October through January over climate type 4. Longer periods (30-year filtered RAI's) have significant negative trend for climate types 2 &4, but positive trend for climate type 5. These trends also occurred during February through May.

Keywords: Long-period rainfall variability, Rainfall variations, RAI

INTRODUCTION

Variations in the distribution of rainfall in space and time are very high and are dependent on the disturbances they are associated with. Some documented results are noted in squall lines, mesoscale convective systems (MCS's), and locally forced precipitation. In squall lines, the zone of mesoscale downdraft could attain a width of 600 km (Zipser, 1969) and rainfall is concentrated where airflow activity is greatest. Mesoscale convective systems have convectional precipitation covering areas up to thousands of square kilometers (Leary & Houze, 1979). Smaller scale and short-lived precipitation originates from locally forced precipitation which develops in response to differential surface heating as in land/sea breeze, warmer large urban areas, and areas of higher elevations.

Large scale rainfall anomalies have been associated with the El Niño and La Niña phenomena. Droughts in the Philippines and other countries in the western Pacific region are observed during El Niño conditions (Estoque et al., 1985; de las Alas & Buan, 1986; Hackert & Hastenrath, 1986) while excessive rains are experienced in the central and eastern Pacific region (Rasmusson & Wallace, 1983; Ropelewski & Halpert, 1987). During La Niña events, the reverse atmospheric conditions are observed. It is noted that rainfall distribution over space and time during either event is highly variable and causes major economic losses due to disastrous typhoons, floods, and droughts.

Another important factor which may alter the variability of rainfall is the enhanced atmospheric greenhouse effect. This is associated with the increase in global air temperature as caused by the increasing concentration of water vapor, CO_2, methane, nitrous oxide, and chloroflourocarbons or CFC's (the so-called greenhouse gases or GHG's). Observations of these GHG's particularly that of CO_2 showed an increasing trend (WMO, 1990). The increase in trend of global mean temperature started since the onset of industrialization. Because of the strong theoretical basis for enhanced greenhouse warming, there is considerable concern about the potential climatic effects that may result.

Various studies have been conducted to understand climate variability observed all over the world. Rainfall, particularly its variability, is interesting because it affects economic activities specially in agricultural countries like the Philippines where rainfed agriculture contributes a high percentage to domestic production. More importantly, the vulnerability of the Philippines to the variability of rainfall may aggravate floodings or droughts in climatically constrained regions in the country. Therefore, statistical interpretation of rainfall variations over space and time in the Philippines is important. It is along this line that this study is conducted.

Previous studies reveal that Philippine rainfall is highly variable both in space and time. For example, de las Alas & Buan (1986) using composites of rainfall anomalies a year before, during, and a year after El Niño invasions in the Philippines showed significant below normal rainfall over Mindanao; however, during strong events negative rainfall anomalies covered a wider area including central and western Visayas and eastern Philippines. Spectrum analyses on Philippine rainfall showed a more pronounced spectra during ENSO period (Jose, 1989; Buan, 1992) with spectral estimates of 90%, 60%, and 50% in Mindanao, Visayas, and Luzon, respectively (Jose, 1989). Strong signals of a quasi-biennial oscillation were also found (Jose, 1989), except for the eastern Philippines and the northern Luzon area (Buan, 1992).

MATERIALS AND METHODS

Monthly rainfall data for the period 1950-1996 observed in 35 synoptic stations distributed across the Philippine archipelago (Figure 1) are used in this study. Surface rainfall observations at meteorological stations in the Philippines as maintained by PAGASA, follow the standard procedure set by the World Meteorological Organization (WMO). Within a prescribed interval of time, i.e., every three hours in synoptic stations, rainfall amount is accumulated in an 8-inch raingauge and measured using a stick with magnified scale usually in millimeters. Each 3-hourly observation is accumulated to obtain the total for the day and then the daily totals are summed up to obtain the total rainfall for the month. Meteorological stations are also equipped with automated rainfall measuring instruments which complement the manually measured rainfall. The observations are regularly checked by the chief meteorological officer in each station, entered into appropriate forms and forwarded to the PAGASA central office for forecasting, research, and other related purposes.

As shown in Figure 1 the largest island, Luzon, is covered by 60% of the entire meteorological stations included in this study; Mindanao has 20%; and the remaining 20% is scattered in the smaller islands of Visayas. For various reasons, the optimum exposure of raingauges are not met in some observing stations particularly those stations located in cities or densely populated areas. Sometimes these stations are relocated to other sites where the environments significantly differ. To minimize the bias inherent in the rainfall data observed over individual stations, (a) a standardized rainfall anomaly of four-month seasons was computed for each station,
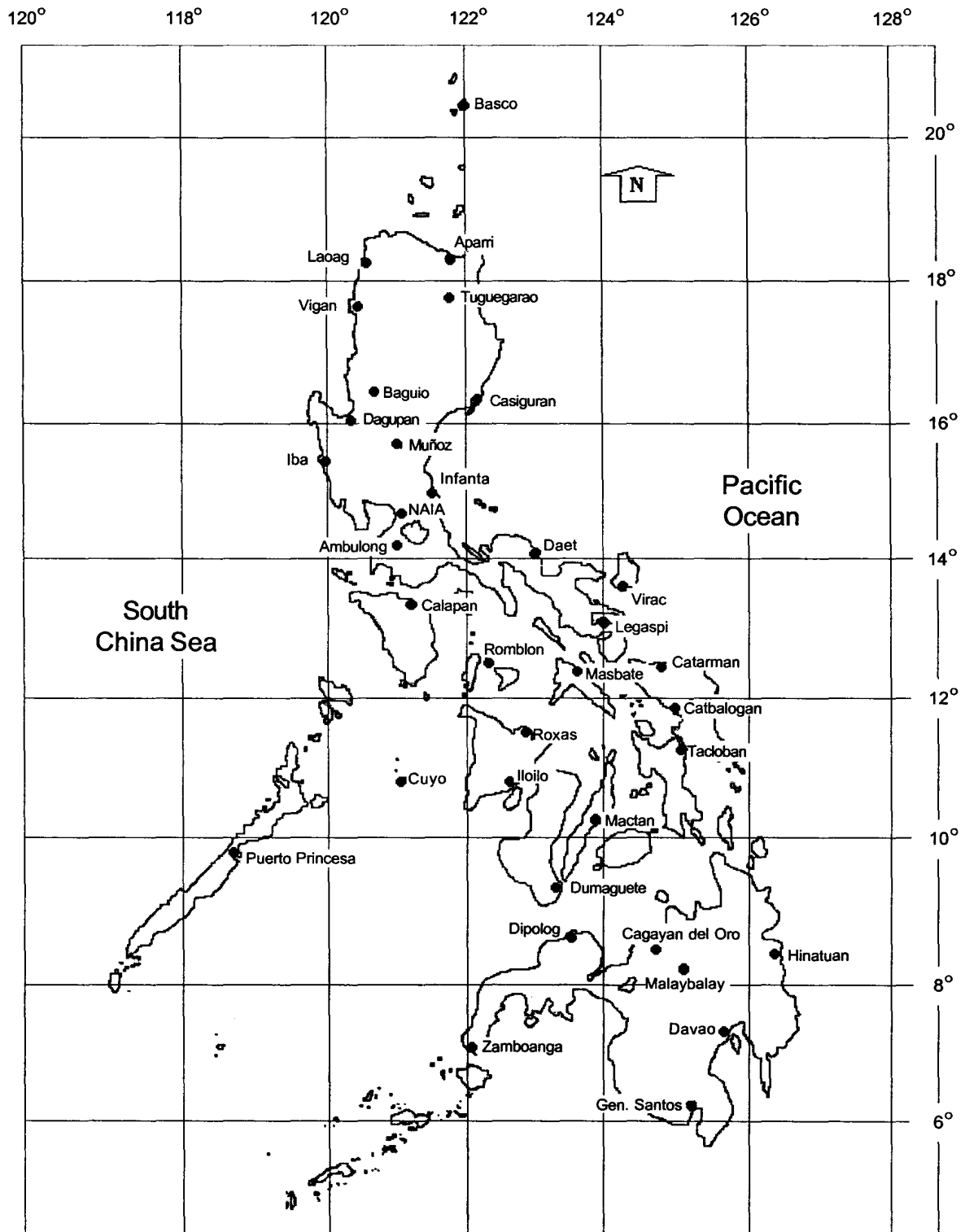
Figure 1. Geographical distribution of synoptic stations included in this study.

and (b) area averaged standardized rainfall anomaly for each four-month season and climate zone was calculated. Some amounts of data are marked as missing and these are filled with the long-period average for the month during the period considered.

In this study, the interstation comparability of rainfall observations was objectively measured. It is imperative to come up with highly correlated rainfall data between stations. The available, long, and unbroken data for small geographic areas as they respond to large-scale weather are averaged to represent an index for monitoring climate fluctuations. For this purpose, the interstation comparability of rainfall observations is measured by the standard deviation (SD), range of SD, and the correlation coefficient. The monthly SD over the entire period is computed as:

$$(1) \quad SD = \sqrt{\frac{\sum_{i=1}^{N}(x-\bar{x})^2}{N-1}}$$

where x is the monthly rainfall total (mm), ξ is the monthly rainfall average and N is the number of years of record. Range (R) of SD is taken as the difference between the highest SD and the lowest SD each year during the whole period, or:

$$(2) \quad R = SD_{max} - SD_{min}$$

The degree of association in the observed rainfall between two stations is determined using the equation of the correlation coefficient (r) as follows:

$$(3) \quad r = \frac{\sum_{i=1}^{N} xy}{\sqrt{\sum_{i=1}^{N} x^2 \sum_{i=1}^{N} y^2}}$$

Where x and y represent the respective rainfall data of the two stations. A matrix of correlation coefficients for all rainfall stations is computed and the test of significance of individual correlation coefficient is estimated from the statistic F which is given by:

$$(4) \quad F = \frac{r^2(N-2)}{1-r^2}$$

where r is the correlation coefficient and N is the number of paired observations.

An interstation correlation coefficient, r, of 0.75 will be maintained while grouping the stations according to the range of SD. The months with maximum average rainfall will also be considered in delineating the climate zones.

After the climate zones are defined, the RAI can now be constructed. The RAI is the composite of the standardized rainfall anomaly for stations that belong to the same climate and is computed as:

$$(5) \quad RAI_{ij} = \frac{1}{N}\frac{\sum_{i=1}^{N}(x_{ij} - \bar{x}_i)}{S_i}$$

where x_{ij} is the rainfall for the period for station i and year j, ξ_i is the average rainfall for the period for station i and S_i is the standard deviation of station i for the period considered.

The 4-month season rainfall and the time series of RAI were computed as follows: Monthly rainfall total for February, March, April and May for each year were summed up to obtain the value for FMAM. In the same manner, the summation of June, July, August and September rainfall for JJAS; and October, November, December and January rainfall of the succeeding year for ONDJ. For each station and period, the average, standard deviation, and the standardized rainfall anomaly are computed.

The following analytical procedures were used to identify the variance structure of the time series of 4-monthly RAI for each climate type:

Skewness, Kurtosis and Chi-square test

To test the null hypothesis that the samples of RAI came from a population with a normal (Gaussian) distribution, the coefficient of skewness, Z_1, the coefficient of kurtosis, Z_2, and the chi-squared test χ^2 are used. These are computed as follows:

$$(6) \quad Z_1 = \frac{\dfrac{N^{-1}\sum\limits_{i=1}^{N}(x_i - \bar{x})^3}{[N^{-1}\sum\limits_{i=1}^{N}(x_i - \bar{x})^2]^{\frac{3}{2}}}}{\sqrt{\dfrac{6}{N}}}$$

$$(7) \quad Z_2 = \frac{\dfrac{N^{-1}\sum\limits_{i=1}^{N}(x_i - \bar{x})^4}{[N^{-1}\sum\limits_{i=1}^{N}(x_i - \bar{x})]^2} - 3}{\sqrt{\dfrac{24}{N}}}$$

If the absolute value of Z_1 or Z_2 is greater than 1.96, a significant skewness or peakedness as compared to the normal curve is indicated at the 95% confidence level.

A test for deviation from the mean and standard deviation, χ^2, is calculated as;

$$(8) \quad \chi^2 = \frac{\sum\limits_{i=1}^{m}(o_i - h_i)^2}{h_i}$$

Where O_i and H_i are the number of individuals in each category in the given and theoretical distribution, respectively. If the absolute value of χ^2 is greater than 11.07 then a significant deviation from the normal distribution is indicated at the 95% confidence level.

Von Neumann ratio

Theoretically, climatological time series may be random, non-random or a sum of both random and non-random components. Assuming that the time series of RAI's is normally distributed, then the von Neumann ratio, V, is utilized to test RAI's randomness against unspecified alternatives (Mitchell, 1966). Von Neumann ratio is given as:

$$(9) \quad V = \left(\frac{N}{N-1}\right)\frac{\sum\limits_{i=1}^{N}(x_i - x_{i+1})^2}{(\sum\limits_{i=1}^{N}x_i^2 - \frac{1}{N})(\sum\limits_{i=1}^{N}x_i)^2}$$

V is then compared with the test statistic, k=2.52 at P=0.95 for N=47 (Hart, 1942) as suggested by Mitchell (1966) in lieu of the test statistic derived from V_t for larger N which is estimated as:

$$(10) \quad V_t = \frac{2N - 2t_g(N-2)^{\frac{t}{2}}}{N-1}$$

For a one-tailed test at the 95% confidence level, t_g=2.52. If V > V_t then the null hypothesis that the time series is random is accepted, however, if V < V_t non-random elements are present in the data.

Mann-Kendall rank statistic

To test the presence of trend (linear or non-linear) in the RAI time series of each climate type, the Mann-Kendall rank statistic, τ, is employed. For N numbers of data in the series, τ is calculated as:

$$(11) \quad \tau = \frac{4\sum_{i=1}^{N-1} n_i}{N(N-1)} - 1$$

where n_i is the number of subsequent terms from X_{i+1} to X_N in the time series that exceed X_i. The value of t is compared to $(\tau)_t$ whose value is calculated as:

$$(12) \quad \tau_t = 0 \pm t_g \sqrt{\frac{4N+10}{9N(N-1)}}$$

where t_g is the two-tailed probability of the Gaussian distribution, equal to 1.96 at the 95% confidence level. If t lies outside the bounds of $(\tau)_t$ then some form of trend exists in the non-random variance structure.

Student's t-test

To test for the significant difference between mean values of the series in two different periods of record, the student's t-test is applied. If the two means in question are denoted by ξ_1 and ξ_2 and the corresponding numbers of values on which each mean is based are denoted respectively by N_1 and N_2, then the test statistic is calculated as:

$$(13) \quad t_d = \frac{\overline{x_2} - \overline{x_1} - (\mu_1 - \mu_2)}{\sqrt{\left(\frac{N_1 S_1^{2} + N_2 S_2^{2}}{N_2 + N_1 - 2}\right)\left(\frac{1}{N_1} + \frac{1}{N_2}\right)}}$$

where μ_1 and μ_2 is the expected difference between ξ_1 and ξ_2. This is set to zero for the case of randomness. S_1 and S_2 are the sample variance of x_1 and x_2. $N_1 S_1^{2}$ is computed from:

$$(14) \quad N_1 S_1^{2} = \frac{\sum_{i=1}^{N_1} x_1^{2} - 1}{N_1(\sum_{i=1}^{N_1} x_1)^2}$$

$N_2 S_2^{2}$ is computed similarly from the above equation. The value of $|t_d|$ is then computed with the 95% probability points of the t-distribution appropriate to a two-tailed form of test. If $|t_d|$ lies beyond the t-value, then the difference between the two sample means indicates an evidence of inconstancy (i.e., non-randomness).

Variance test of rainfall anomalies

To gain confidence in the RAI, Kraus (1977) suggested, that it be shown that the geographical variations of the standardized rainfall anomalies between stations within the climate type are small compared to the temporal year-to-year variations. The variance in time, V_t, which characterizes the year-to-year fluctuations is computed as:

$$(15) \quad V_t = \frac{N - \sum_{i=1}^{N} I_i a_i^{2}}{N - J}$$

where I_j is the number of rainfall stations operative in year j, a_j^{2} is the square of the RAI and J is the number of years of record.

The mean geographical variance between the rainfall anomalies within the climate type is given by:

$$(16) \quad V_a = \frac{\sum_{i=1}^{N} I_i a_i^{2}}{J - 1}$$

where N is the total number of station years.

Low Pass Filters

Two filters are utilized to understand further the trend of the rainfall anomaly. The equation of these filters is of the general form:

$$(12) \quad \overline{x_t} = \sum_{i=-n}^{+n} w_i x_{ti}$$

where ξ_t is the filtered value, w_i is the corresponding weight of rainfall at the period and year i, and x_{ti} is the rainfall for the period and year i.

The first filter is an ordinary moving average of a ten-year succession of rainfall data. As such it has a constant weight which is equal to $1/(2n+1)$, where $2n+1$ is equal to 10. Hence, weight (w) in a ten-year moving average is 0.10. The second filter is the 30-year moving average which is considered long enough to have a good representation of wet and dry periods. Therefore, using a 30-year moving average will smoothen the long-term irregularities caused by wet and dry periods and a trend revealed.

RESULTS AND DISCUSSIONS

Climate classification

Standard deviation (SD), correlations (r) and significant test (F).

Figure 2 summarizes the SD of monthly total rainfall for the 35 stations. Generally, SD's are high during the rainy months and low in the dry months (Fig. 2). Referring to Table 1, Baguio has the highest SD range of 704 followed by Iba (484) and Vigan (347). These stations have significantly higher monthly rainfall during the SW monsoon. Stations with higher rainfall during the NE monsoon months have lesser range of SD, e.g., Virac (249.8), Hinatuan (240.4) and Daet (226.3). The least variable rainfall are recorded in Davao, Malaybalay, and Dumaguete. These stations have respective SD ranges of 30.6, 42.4, and 43.9 (Table 1).

Table 2 shows the matrix of correlation coefficients for all stations. One observation from these values is that stations whose rainfall are highly influenced by the NE monsoon are highly correlated to each other, e.g., Basco, Aparri, Tuguegarao, Romblon, Cagayan de Oro, and Malaybalay. Similarly, the stations Vigan, Laoag, Iba,
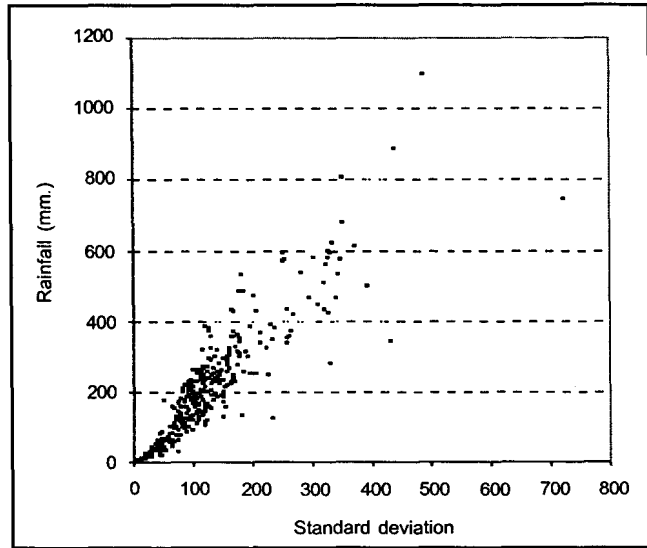

Figure 2. Standard deviation of monthly rainfall.

Dagupan, Baguio, Munoz, NAIA, Ambulong, Cuyo, and Iloilo which are dominated by the southwest monsoon are also highly correlated to each other. The stations Vigan and Laoag have the highest correlation coefficient while Catarman and Vigan have the lowest. The proximity between Laoag and Vigan in addition to their good exposure to the same air stream is a physical reason of their high degree of association. This is also observed between the stations Dagupan and Baguio, NAIA and Ambulong, Daet and Virac, Catbalogan and Tacloban, and Cagayan de Oro and Malaybalay.

The F value (equation 4) for the lowest correlation coefficient (0.363) is 28.236. The limiting values of F at 1 and 186 degrees of freedom are 6.77 and 3.90 for 1% and 5% probability level respectively (Table 19, Panofsky and Brier, 1965). This value ($F=28.236$) statistically means that the probability of the paired values originating from uncorrelated population is less than 1%. Clearly, equation 4 indicates that F varies directly with r, hence, it follows that all other r values gave high probability of correlation.

The Climate Zones

Obviously, Philippine rainfall is dominated by the impact of the SW and NE monsoon airstreams (Figs. 3a to 3e). Prerequisite to the calculation of RAI's are high

NOTE: To conserve space only the first four letters of each station name are reflected.

Station Index

Month	Basc	Viga	Laoa	Apar	Tugu	Iba	Dagu	Bagu	Muno	Casi	NAIA	Cata	Ambu	Infa	Daet	Lega	Vira	Romb
Jan	88.5	6.2	8.6	90.9	25.6	6.2	9.8	48.7	12.2	135.2	14.1	71.2	32.0	131.6	181.2	163.8	139.9	67.8
Feb	72.9	6.3	3.5	58.7	21.4	5.5	12.2	20.3	9.5	150.8	6.6	44.4	13.8	142.0	111.5	112.7	73.1	30.0
Mar	84.7	13.0	4.9	42.1	29.1	18.0	27.2	38.7	24.8	132.2	10.3	59.7	24.8	119.1	111.3	137.3	76.1	51.0
Apr	63.9	31.9	46.0	34.0	47.9	32.3	47.3	73.8	46.5	111.0	23.4	84.6	32.3	151.7	98.3	125.0	112.3	67.1
May	124.0	131.4	122.1	94.5	79.0	332.2	152.3	225.1	154.6	172.2	121.8	109.8	152.7	158.0	109.0	103.7	136.1	100.6
Jun	205.7	230.8	258.1	128.5	85.0	351.3	235.7	343.8	148.2	118.3	168.3	100.5	138.0	133.2	98.3	115.7	148.2	94.5
Jul	163.9	345.6	329.7	149.2	115.7	354.5	393.8	723.8	174.6	135.1	260.2	119.4	189.9	141.0	106.1	105.7	106.1	118.3
Aug	270.5	353.3	257.0	146.4	145.7	489.4	303.7	440.5	122.7	115.1	206.6	118.5	162.7	106.7	116.4	114.5	99.7	95.8
Sep	265.9	197.8	237.4	123.6	120.6	337.2	167.3	373.8	116.7	159.1	159.2	131.5	133.9	160.3	100.1	117.5	122.7	127.3
Oct	215.9	123.6	108.6	171.0	158.1	228.6	120.0	433.7	143.2	298.1	156.5	138.0	152.1	328.1	180.9	180.4	215.5	177.0
Nov	193.0	50.1	51.1	263.8	209.3	90.3	61.7	183.4	94.1	329.4	75.1	171.1	104.9	253.7	251.3	187.7	203.2	122.8
Dec	185.7	18.9	20.8	114.4	87.9	76.8	19.9	26.3	48.1	312.8	43.8	152.2	89.9	332.5	324.6	321.3	322.9	138.7
Range	206.6	347.1	326.2	229.8	187.9	483.9	384.0	703.5	165.1	218.4	253.6	126.7	176.1	225.8	226.3	217.6	249.8	147.0

Station Index

Month	Roxa	Masb	Cata	Catb	Tacl	Puer	Cuyo	Iloi	Duma	Mact	Dipo	Caga	Mala	Dava	Hina	Zamb	Gene
Jan	82.4	135.5	260.9	165.8	176.9	28.5	27.0	40.1	70.7	79.5	106.5	100.5	85.7	66.3	322.1	45.0	40.9
Feb	30.4	65.6	138.8	88.5	111.0	27.0	6.7	21.3	43.0	55.5	50.8	55.0	68.9	61.1	230.4	42.0	41.7
Mar	49.4	79.4	164.7	110.6	103.2	56.9	20.4	45.4	51.4	46.8	72.4	45.0	77.9	67.3	161.2	34.4	31.6
Apr	76.9	70.4	120.4	81.7	82.2	39.4	65.0	66.7	47.0	59.5	77.4	43.5	81.8	83.7	166.2	56.7	38.4
May	118.0	122.7	79.4	110.0	92.4	79.9	97.8	110.0	58.9	71.9	103.8	72.3	88.3	86.9	112.7	43.3	44.1
Jun	133.3	69.1	88.7	101.3	64.8	88.2	129.6	128.2	69.8	86.3	109.0	84.8	89.6	88.5	111.3	81.1	81.3
Jul	114.4	93.4	93.3	113.7	76.2	52.1	166.6	161.6	69.7	80.9	100.3	88.3	102.7	83.3	81.7	67.0	69.5
Aug	96.3	87.8	90.2	98.2	74.9	77.3	170.2	189.3	52.4	86.0	90.2	82.4	102.9	83.4	82.1	75.3	50.2
Sep	116.7	97.8	125.0	124.9	79.5	99.2	129.6	145.5	86.9	86.7	93.0	93.6	109.9	81.5	84.8	102.0	47.2
Oct	140.5	130.0	179.7	178.4	104.1	95.6	151.7	146.5	79.4	82.4	133.3	78.9	111.3	74.5	106.3	138.4	61.9
Nov	141.8	114.1	183.6	132.5	116.6	115.2	116.6	107.7	86.0	89.6	178.2	99.5	89.3	57.9	161.1	121.2	44.4
Dec	120.8	196.3	284.0	162.3	162.4	135.2	64.4	69.8	78.0	92.4	158.0	85.6	95.3	61.8	240.5	154.8	47.5
Range	111.4	130.7	204.6	96.7	112.1	108.2	163.5	148.0	43.9	45.6	127.6	57.0	42.4	30.6	240.4	120.4	49.7

Table 1. Standard deviation of monthly total rainfall (1950-1996) for the 35 rainfall stations.

	Basc	Viga	Laoa	Apar	Tugu	Iba	Dagu	Bagu	Muno	Casi	NAIA	Cala	Ambu	Infa	Daet	Lega	Vira
Basc	1.00																
Viga	.682	1.000															
Laoa	.682	.969	1.000														
Apar	.815	.611	.629	1.000													
Tugu	.815	.731	.743	.901	1.000												
Iba	.692	.891	.888	.623	.745	1.000											
Dagu	.699	.929	.901	.602	.730	.900	1.000										
Bagu	.712	.926	.897	.623	.760	.874	.964	1.000									
Muno	.747	.908	.894	.718	.829	.930	.936	.920	1.000								
Casi	.727	.429	.454	.831	.835	.499	.491	.488	.620	1.000							
NAIA	.725	.872	.860	.690	.791	.907	.924	.890	.928	.599	1.000						
Cala	.786	.599	.625	.807	.839	.649	.624	.619	.735	.877	.713	1.000					
Ambu	.769	.841	.836	.759	.854	.852	.874	.871	.929	.726	.585	.817	1.000				
Infa	.731	.415	.420	.828	.795	.470	.477	.489	.600	.944	.562	.870	.709	1.000			
Daet	.743	.386	.403	.857	.786	.480	.449	.456	.568	.900	.627	.841	.672	.928	1.000		
Lega	.775	.475	.487	.823	.806	.536	.547	.555	.652	.914	.592	.892	.756	.927	.941	1.000	
Vira	.780	.435	.448	.818	.782	.509	.499	.494	.618	.892	.769	.889	.708	.896	.943	.935	1.000
Romb	.812	.641	.653	.855	.855	.694	.681	.669	.777	.878	.751	.923	.856	.864	.866	.902	.876
Roxa	.788	.632	.644	.848	.859	.677	.668	.653	.768	.870	.751	.902	.836	.854	.850	.886	.864
Masb	.767	.564	.571	.826	.829	.630	.615	.618	.721	.856	.690	.880	.788	.873	.876	.907	.884
Cata	.716	.363	.376	.787	.730	.417	.423	.444	.542	.868	.509	.850	.640	.920	.911	.923	.915
Catb	.777	.557	.577	.816	.803	.588	.607	.622	.699	.858	.678	.901	.788	.881	.867	.921	.876
Tacl	.724	.458	.465	.777	.764	.483	.511	.537	.620	.862	.578	.873	.711	.909	.849	.921	.858
Puer	.797	.674	.683	.836	.842	.720	.700	.680	.792	.824	.765	.870	.835	.828	.829	.880	.828
Cuyo	.746	.845	.861	.741	.816	.872	.831	.817	.915	.657	.868	.787	.902	.626	.612	.692	.654
Iloi	.774	.810	.833	.758	.831	.838	.833	.814	.898	.700	.848	.832	.915	.685	.665	.753	.714
Duma	.776	.570	.587	.838	.832	.603	.602	.600	.712	.851	.654	.861	.761	.841	.850	.873	.857
Mact	.773	.675	.697	.818	.854	.701	.705	.695	.787	.839	.761	.892	.848	.821	.810	.854	.814
Dipo	.796	.565	.571	.875	.844	.628	.618	.615	.728	.866	.687	.877	.780	.894	.896	.913	.888
Caga	.811	.751	.758	.814	.856	.770	.767	.754	.847	.781	.807	.855	.854	.785	.778	.826	.791
Mala	.820	.731	.746	.793	.839	.746	.769	.753	.830	.789	.790	.874	.854	.790	.775	.836	.798
Dava	.765	.646	.665	.754	.777	.655	.693	.678	.748	.810	.714	.851	.785	.805	.772	.834	.795
Hina	.698	.392	.396	.741	.705	.411	.449	.471	.532	.830	.504	.786	.635	.864	.839	.878	.835
Zamb	.683	.565	.574	.704	.728	.621	.605	.597	.708	.719	.676	.785	.782	.749	.728	.787	.736
Gene	.751	.642	.647	.769	.798	.629	.641	.633	.737	.784	.672	.836	.758	.793	.767	.823	.786

Table 2. Matrix of interstation correlation coefficients of 4-monthly rainfall for the 35 stations.

NOTE: To conserve space only the first 4 letters of each station name are reflected.

	Romb	Roxa	Masb	Cata	Catb	Tacl	Puer	Cuyo	Iloi	Duma	Mact	Dipo	Caga	Mala	Dava	Hina	Zamb
Romb	1.00																
Roxa	.942	1.000															
Masb	.899	.886	1.000														
Cata	.828	.825	.916	1.000													
Catb	.902	.885	.928	.924	1.000												
Tacl	.841	.831	.896	.933	.937	1.000											
Puer	.917	.923	.857	.796	.877	.809	1.000										
Cuyo	.829	.842	.755	.593	.754	.663	.862	1.000									
Iloi	.859	.837	.821	.663	.805	.742	.841	.912	1.000								
Duma	.908	.906	.870	.836	.877	.835	.885	.777	.797	1.000							
Mact	.910	.910	.865	.795	.893	.840	.886	.852	.874	.906	1.000						
Dipo	.915	.915	.888	.880	.907	.873	.921	.783	.802	.931	.897	1.000					
Caga	.889	.907	.841	.751	.838	.795	.919	.896	.876	.883	.920	.885	1.000				
Mala	.909	.909	.845	.758	.870	.812	.915	.875	.879	.885	.929	.891	.941	1.000			
Dava	.853	.847	.812	.783	.872	.830	.860	.798	.803	.860	.875	.856	.875	.912	1.000		
Hina	.786	.755	.802	.862	.846	.898	.755	.561	.641	.827	.773	.835	.739	.769	.840	1.000	
Zamb	.796	.801	.754	.721	.799	.767	.829	.753	.779	.789	.808	.836	.798	.792	.773	.741	1.000
Gene	.841	.842	.812	.783	.840	.814	.855	.777	.778	.859	.847	.866	.856	.868	.860	.802	.746

Table 2. Matrix of interstation correlation coefficients of 4-monthly rainfall for the 35 stations.

Critical Value (1 - Tail, .05) = + or - .12037
Critical Value (2 - Tail, .05) = +/-   .14314

N = 188

interstation correlations, hence, this rainfall zoning is made. By maintaining an interstation correlation coefficient of 0.75, 3 climate types grouped according to the range of SD are delineated as follows: SD range<100 (low), SD from 100 to 147 (medium), and SD range>147 (high). There were three types that have SD range greater than 147 and these are subdivided according to the month of maximum rainfall (Fig. 3a to 3e). The climate zones as reflected in Figure 4 are as follows:

Type 1. Maximum rainfall falls from July through August and has nearly zero rainfall from December through April (Fig. 3a). SD range is high. These areas are situated in the western sections of the country and are represented by the stations Vigan, Laoag, Iba, Dagupan, Baguio, Munoz, NAIA, Ambulong, Cuyo and Iloilo.

Type 2. Maximum rainfall months occur from October through January. In most stations, dry months fall from March to May (Fig. 3b). SD range is also high. These stations are located in the eastern sections of the country like Casiguran,

Infanta, Daet, Legaspi, Virac, Catarman and Hinatuan.

Type 3. Most stations have higher rainfall amounts June through December-January (Fig. 3c). This climate type has the least variable monthly rainfall throughout the year, hence, SD range is low. Under this type are the stations Catbalogan, Dumaguete, Mactan, Cagayan de Oro, Malaybalay, Davao and General Santos.

Type 4. Maximum rain period occurs from October to December (Fig. 3d) with a medium SD range. This type includes the following stations: Calapan, Romblon, Roxas, Masbate, Tacloban, Puerto Princesa, Dipolog and Zamboanga.

Type 5. Maximum rain period falls from August through November. Dry months are from January to April (Fig. 3e). SD range is also high. These stations are in the extreme north of Luzon like Basco, Aparri and Tuguegarao.
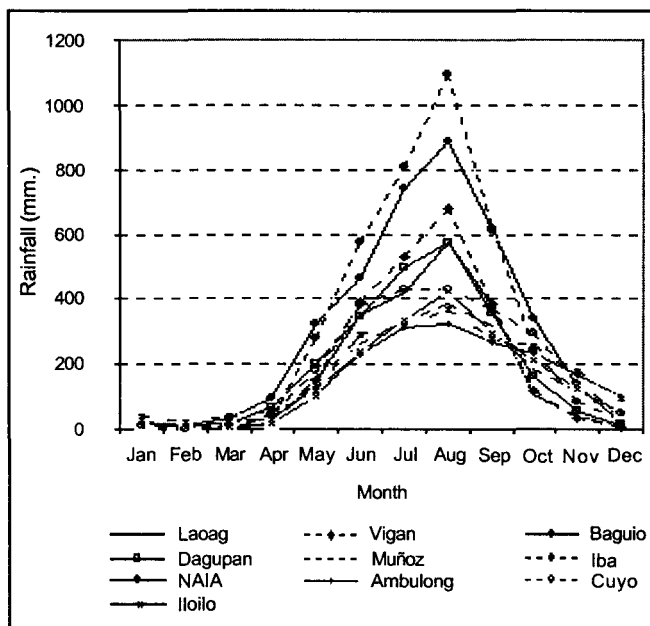
Fig. 3a. Averages of monthly total rainfall for stations under climate type 1.
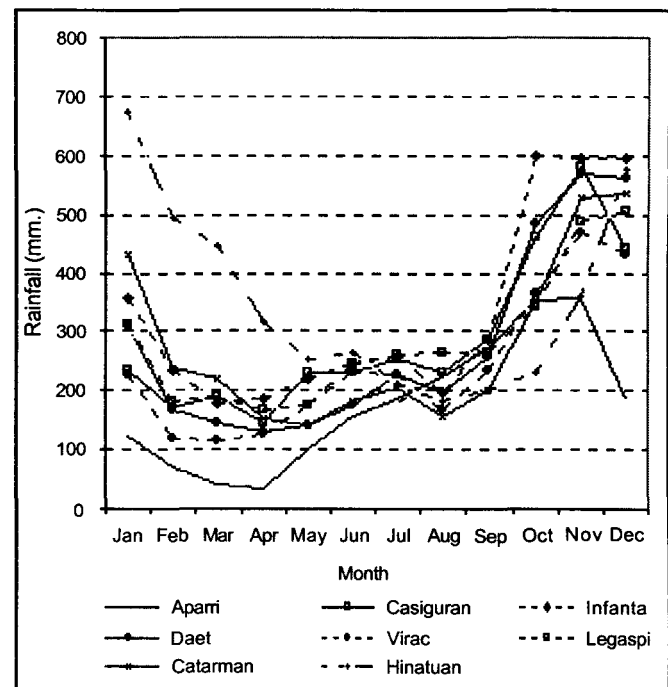
Fig. 3b. Averages of monthly total rainfall for stations under climate type 2.
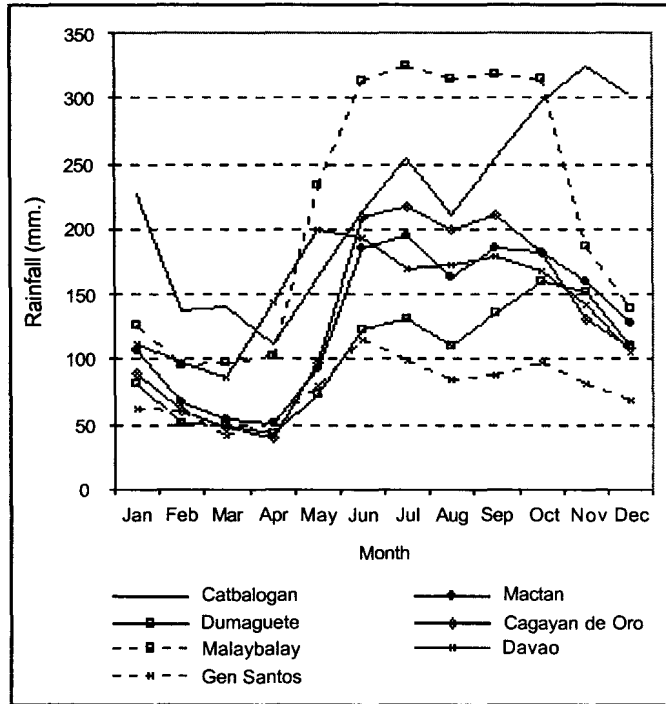
Fig. 3c. Averages of monthly total rainfall for stations under climate type 3.
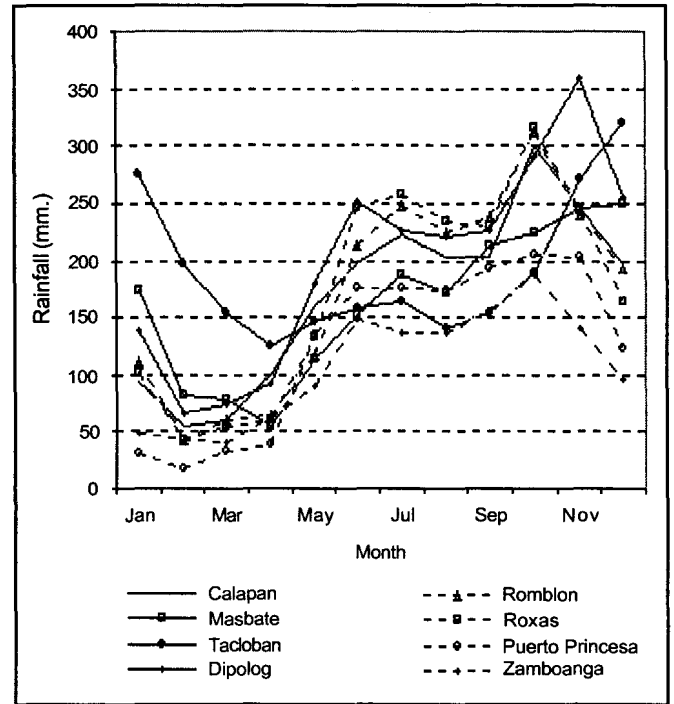
Fig. 3d. Averages of monthly total rainfall for stations under climate type 4.
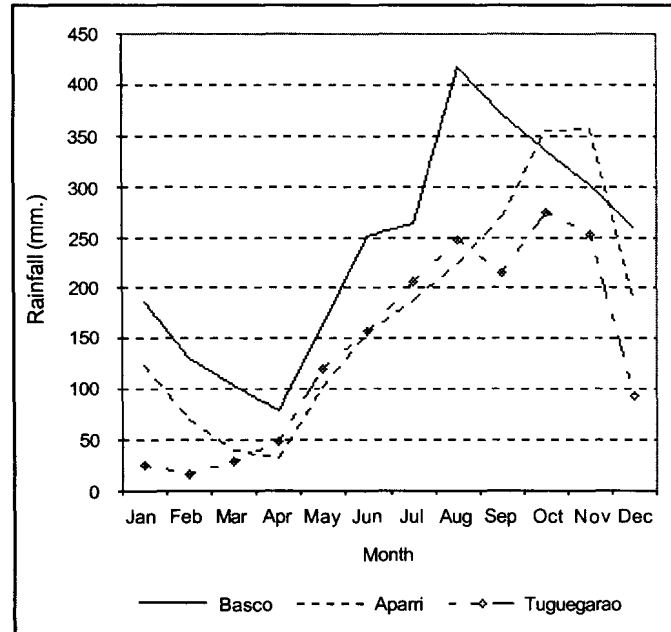
Fig. 3e. Averages of monthly total rainfall for stations under climate type 5.

Variance test of rainfall anomalies

Values of V_t and V_a are shown in Table 4. An F-test on this variance estimates showed that all ratio are highly significant as the limiting values of F for 1% - and 5% probability for all N-J degrees of freedom are lower than the ratios of the variance estimates (Table 5). Although climate type 5 has the lowest variance ratio, it is within the highly significant level which means that there is also coherence in these stations as the other stations within each climate zone. In other words, the probability that differences between years in each climate type can be accounted for by random fluctuations at a few individual stations is substantially less than 1%.

Description of the RAI time series

Unfiltered RAI

Time series graphs of unfiltered RAI for each climate type are shown in Figures 5a to 5e. In these figures,
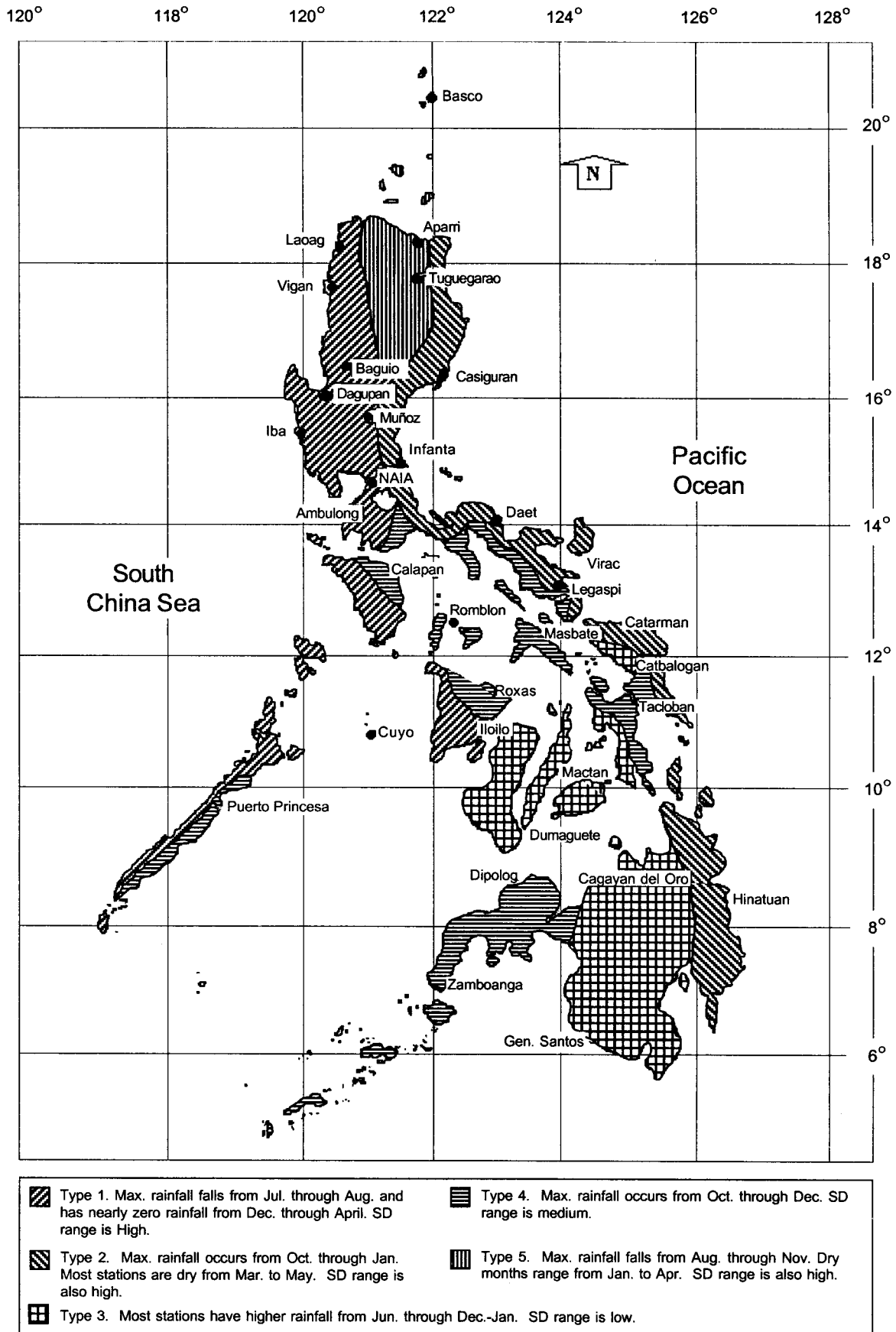
Figure 4. Climate of the Philippines according to interstation correlations, standard deviation, and period of maximum rainfall.

Climate Type	Representative Station (Index)	SD Range		General Description of the area
		Station	Group	
1	* Laoag City, Ilocos Norte (223) * Vigan, Ilocos Sur (222) * Iba, Zambales (324) * Dagupan City, Pangasinan (325) * Baguio City, Benguet (328) * Muñoz, Nueva Ecija (329) * NAIA, Pasay City (429) * Ambulong, Batangas (432) * Cuyo, Palawan (630) * Iloilo City, Iloilo (637)	326.2 347.1 483.9 384.0 703.5 165.1 253.6 176.1 163.5 148.0	>147	Maximum rainfall falls from July-August and has nearly zero rainfall from December-April. SD range is high.
2	* Casiguran, Quezon (336) * Infanta, Qurzon (434) * Daet, Camarines Norte (440) * Legaspi City, Albay (444) * Virac, Catanduanes (446) * Catarman, Northern Samar (546) * Hinatuan, Surigao del Sur (755)	218.4 225.8 226.3 217.6 249.8 204.6 240.4	>147	Maximum rainfal occurs from October-January. Most stations are dry from March-May. SD range is also high.
3	* Catbalogan, W. Samar (548) * Dumaguete, Negros Or. (642) * Mactan, Cebu (646) * Cagayan de Oro, Mis. Or. (748) * Malaybalay, Bukidnon (751) * Davao City, Davao del Sur (753) * Gen. Santos, S. Cotabato (851)	96.7 43.9 45.6 57.0 42.4 30.6 49.7	<100	No maximum period. This covers Central Mindanao and some areas in the Souther and Eastern Visayas.
4	* Calapan, Oriental Mindoro (431) * Romblon (536) * Roxas City, Aklan (538) * Masbate, Masbate (543) * Tacloban City, Leyte (550) * Puerto Princesa, Palawan (618) * Dipolog, Zamboanga del Norte (741) * Zamboanga del Sur (836)	126.7 147.0 111.4 130.7 112.1 108.2 127.6 120.4	100 to 147	Most stations have higher rainfall from January through December-January. SD range is low.
5	* Basco, Batanes (135) * Aparri, Cagayan (232) * Tuguegarao, Cagayan (233)	206.6 229.8 187.9	>147	Maximum rainfall falls from August-November. Dry range from January-April. SD range is also high.

Table 3. Some detailed information on the climate types shown in Figure 4.

Climate Type	Variance			Degrees of Freedom	
	V_t	V_a	V_t/V_a	N-J	J-1
1	3.9	0.6	6.2	423	46
2	4.1	0.4	9.3	282	46
3	3.4	0.5	6.3	282	46
4	3.7	0.6	6.6	329	46
5	1.4	0.6	2.6	94	46

Table 4. Variance estimates of temporal, V_t and spatial V_a of rainfall anomalies according to climactic type.

episodes of El Niño and La Niña (http://nic.fb4.noaa.gov) from 1950-1996 are superimposed. These are respectively marked as EN and LN. It is quite noticeable from the figures that for all climate types, the El Niño of 1972/73, 1982/83, and 1994/95 displayed prolonged dry conditions from October until May, except in 1982 for type 5 climate. During these three events widespread drought was experienced all over the country and the worst was reflected along the eastern sections (climate type 2) and part of the central Visayas and central Mindanao (climate type 3) from
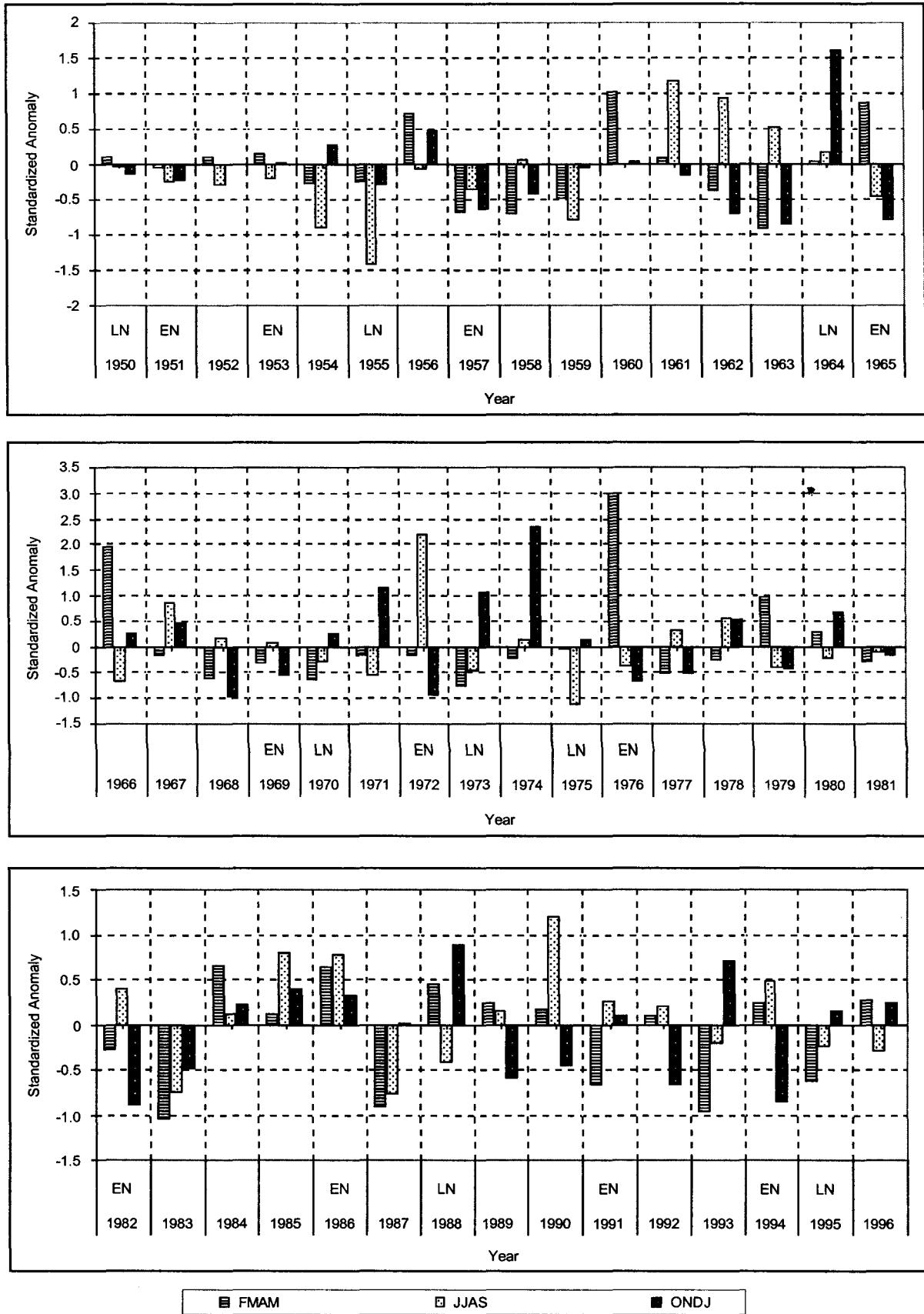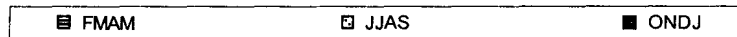
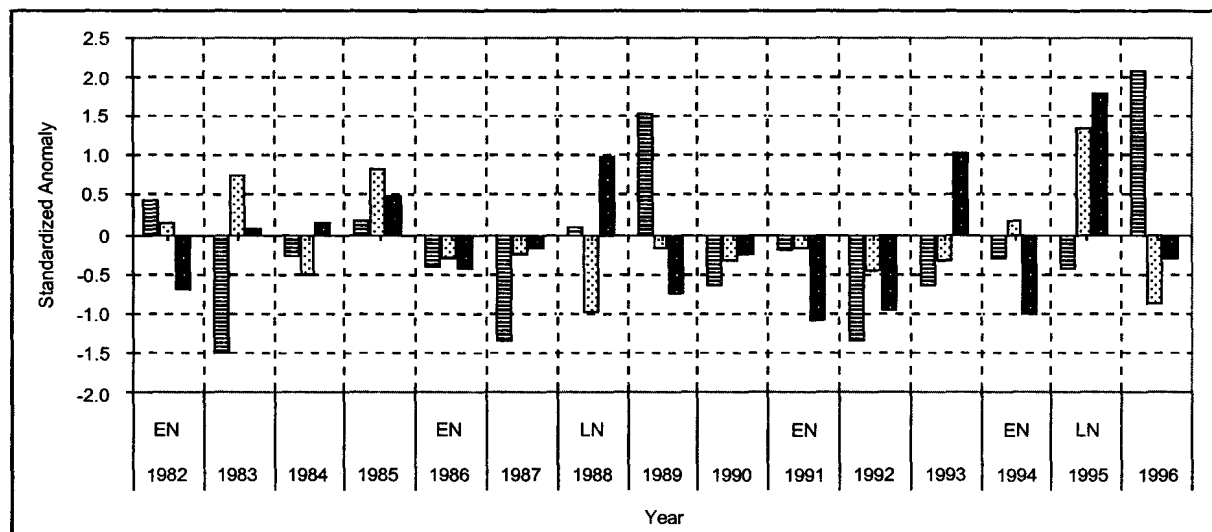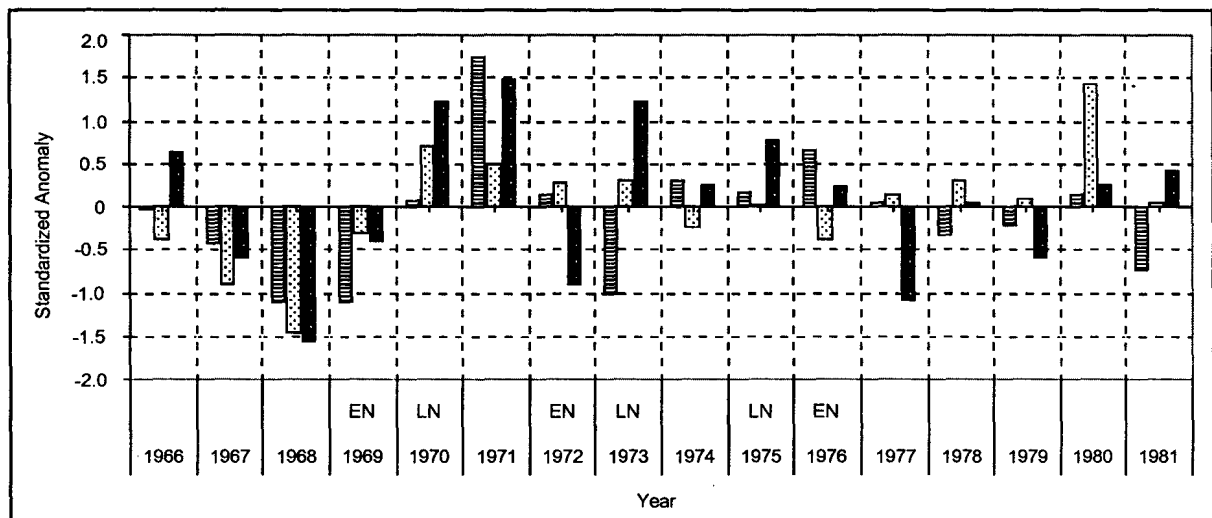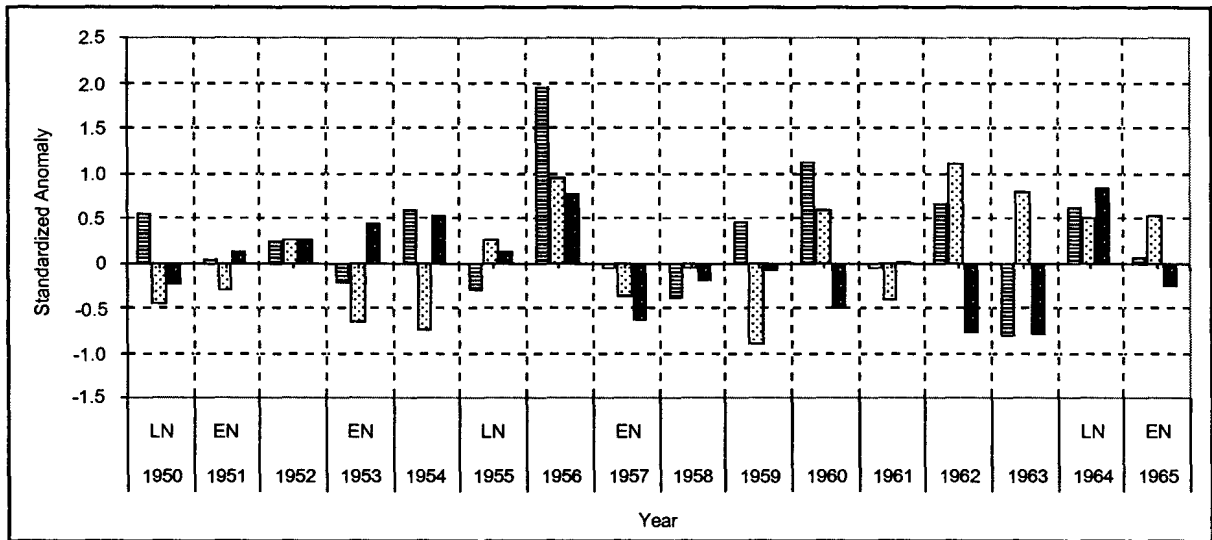Figure 5a. Time series graph of RAI's for type 1 climate.
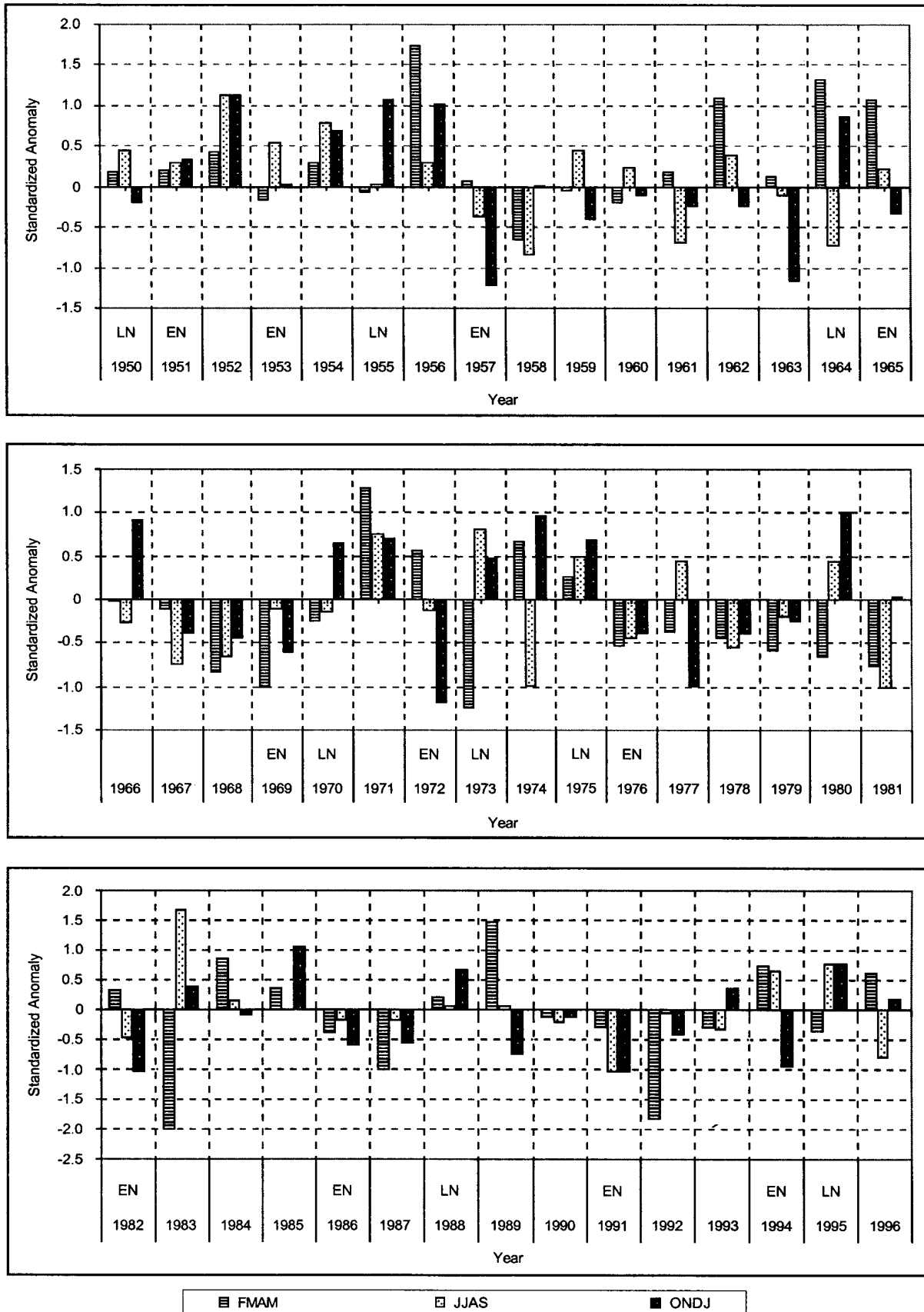
Pajuelas

Figure 5b. As in 5a but for type 2 climate.
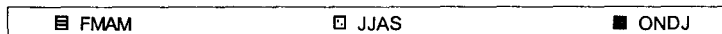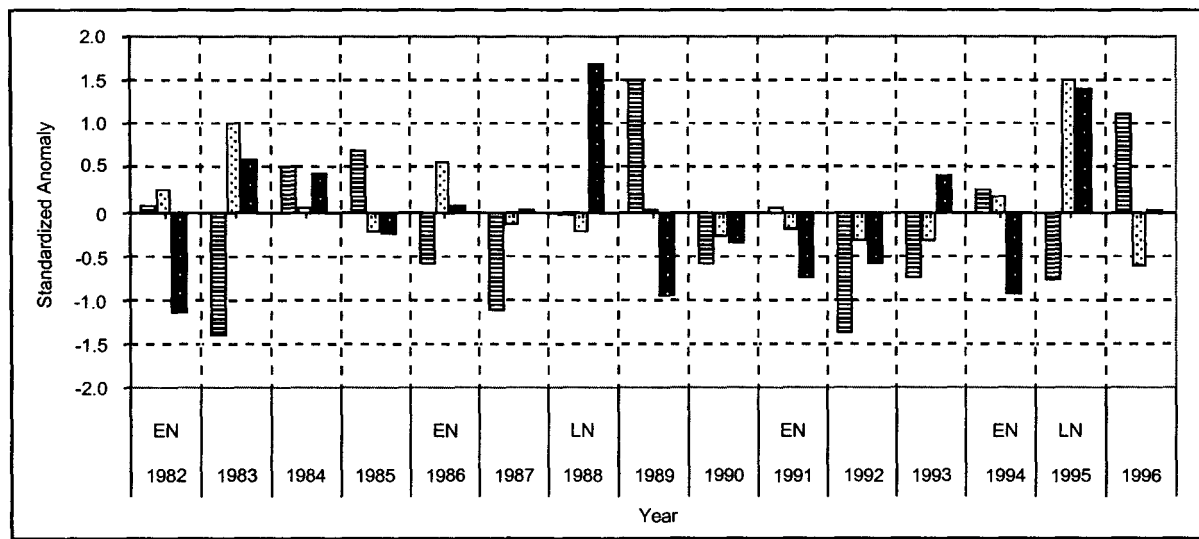
16

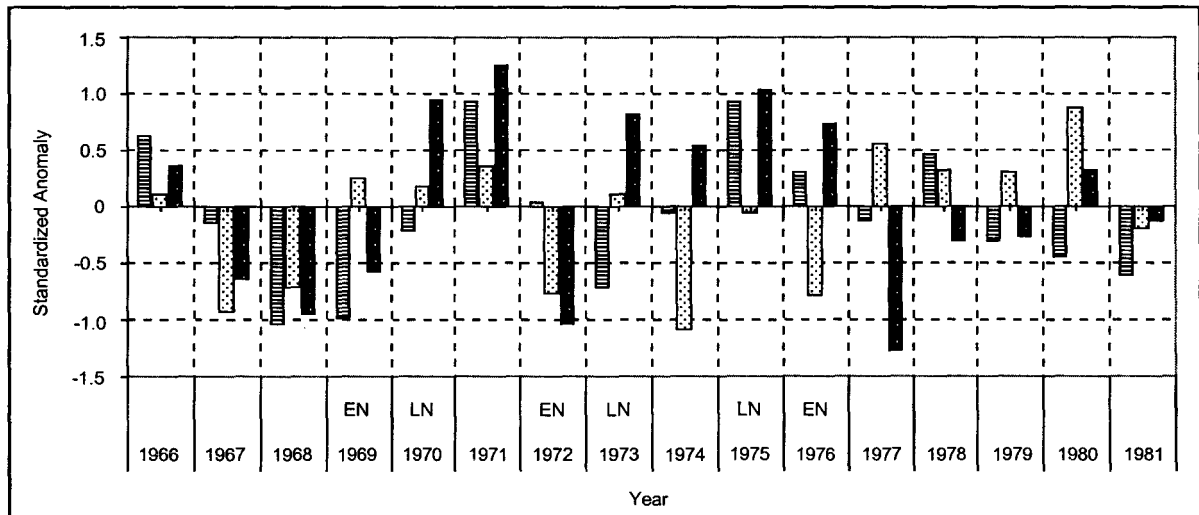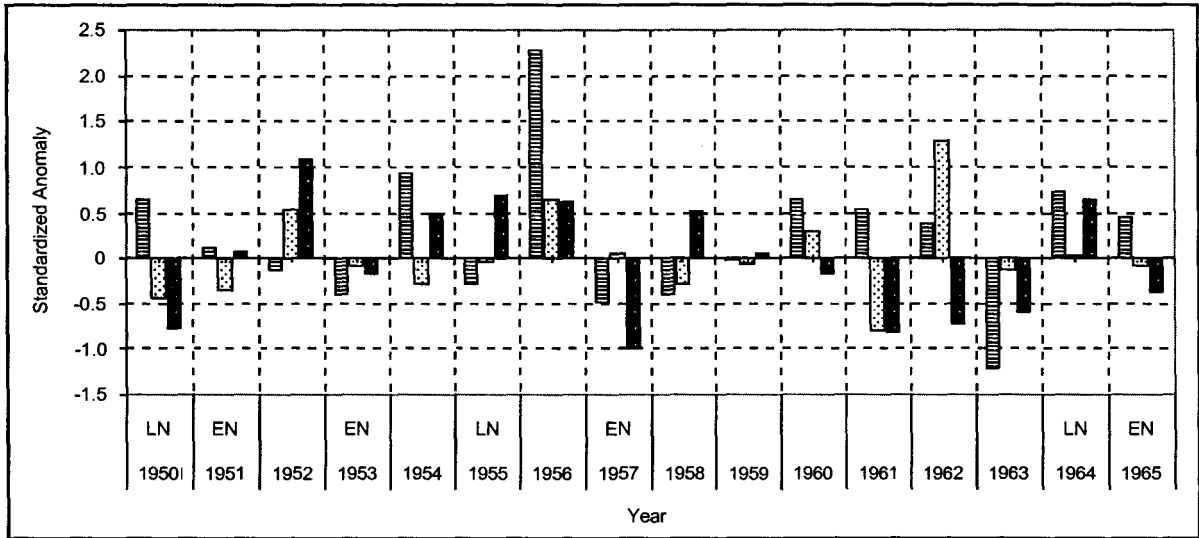Figure 5c. As in 5a but for type 3 climate.

Pajuelas
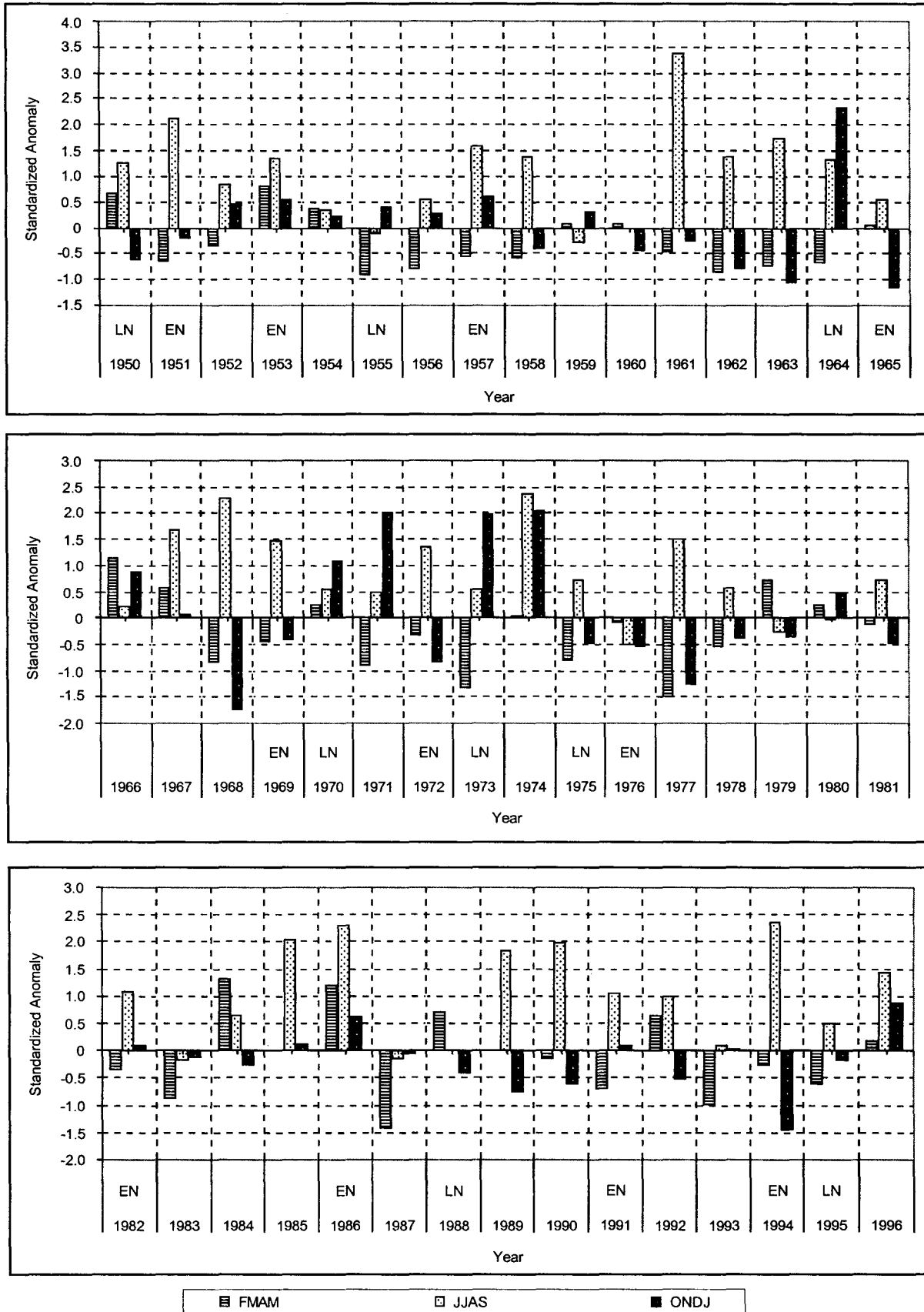

Figure 5d. As in 5a but for type 4 climate.

Figure 5e. As in 5a but for type 5 climate.

February 1983 until May 1983. The impact of La Niña is not a definite positive anomaly for all climate types. For instance, the first event of FMAM 1950 has all the climate types with positive anomaly but not for the remaining months. From these episodes, the La Niña of 1975/76 has the highest rainfall anomaly for climate type 1 (3.0 SD) from February to May 1976.

Statistical characteristics are summarized in Table 6. The assumption that the samples of the RAI came from a population with a Gaussian distribution is tested using the coefficient of skewness, Z_1, the coefficient of kurtosis, Z_2, and the chi-square test, χ^2. In Table 6, by comparing with the test statistic, Z_1 and Z_2 values suggest that except for climate type 1, all other samples of RAI time series do not differ significantly from the normal distribution. RAI's of climate type 1 are positively skewed and have significant degree of peakedness specifically the FMAM series. However, χ^2 indicates that all samples do not significantly differ from the normal distribution. The Von Neumann ratio, V, suggests that non-random elements are significantly present in each time series, but, Mann-Kendall rank statistics, τ, reveals that the presence of trend is not significant. A test for change in the means of two periods using student's t-test showed that there is a significant change in the mean values of the RAI between 1950/72 and 1973/96 for FMAM series for climate type 3 ($t = 2.01$). Other FMAM series like climate types 4 and 2 have high t values also but these are not significant.

Filtered RAI

To explore various aspects of rainfall variabilities, the RAI's were subjected to 10-year and 30-year moving averages. These filters smoothen out variabilities of less than 10 years and 30 years, respectively.

Percent Probability	Degrees of Freedom			
	94	282	329	423
5	1.53	1.50	1.46	1.47
1	1.85	1.79	1.74	1.75

Table 5. Limiting Values of F at the indicated degrees of freedom and % probability level.

In figures 6a to 6e, the 10Y-MA filtered RAI's show fewer wet and dry periods and some trend is revealed. Descriptive statistics of the RAI samples are shown in Table 7 and discussed in the following statements. Some significant skewness (column Z_1) and significant deviation from the normal (column χ^2) are suggested, but, there are no significant peakedness (Z_2 column). Non-random elements are significantly present in all samples (column V) and significant trends are reflected (τ). The decreased trend is manifested by significantly lower average in the second half of the FMAM series for climate types 1, 2, and 5 and ONDJ for type 4 (column t). On the contrary, the FMAM series of climate type 4 has significantly higher average in the second half of the series.

The removal of less than 30 years of fluctuations accentuated some trend in the RAI time series (Figs. 7a to 7e). According to Table 8, these filtered values have significant skewness (Z_1) and peaks (Z_2), but chi-square test (χ^2) suggested that some filtered RAI samples are not significantly different from the normal distribution. Non-random elements are significantly present in some of these samples (V) with significant trends (τ) towards the sensitive months (i.e., October through May) during El Niño and La Niña events. The significant negative trends indicate more deficient rainfall over the eastern and southern parts of Luzon (climate types 2 & 4). But, over the vicinity of Cagayan Valley and the Batanes group of islands (climate type 5), the trend is positive at least from February through May with significantly higher means during the second half of the RAI series.

CONCLUSIONS

Stations within each climate type indicated high interstation correlations of four monthly total rainfall for the period 1950-1996. F-test suggests that the geographical variations of standardized rainfall anomaly is insignificant as compared to the temporal variations within each climate type, which means that the Rainfall Anomaly Index (RAI's) are representative of each climatic region and can be used with confidence.

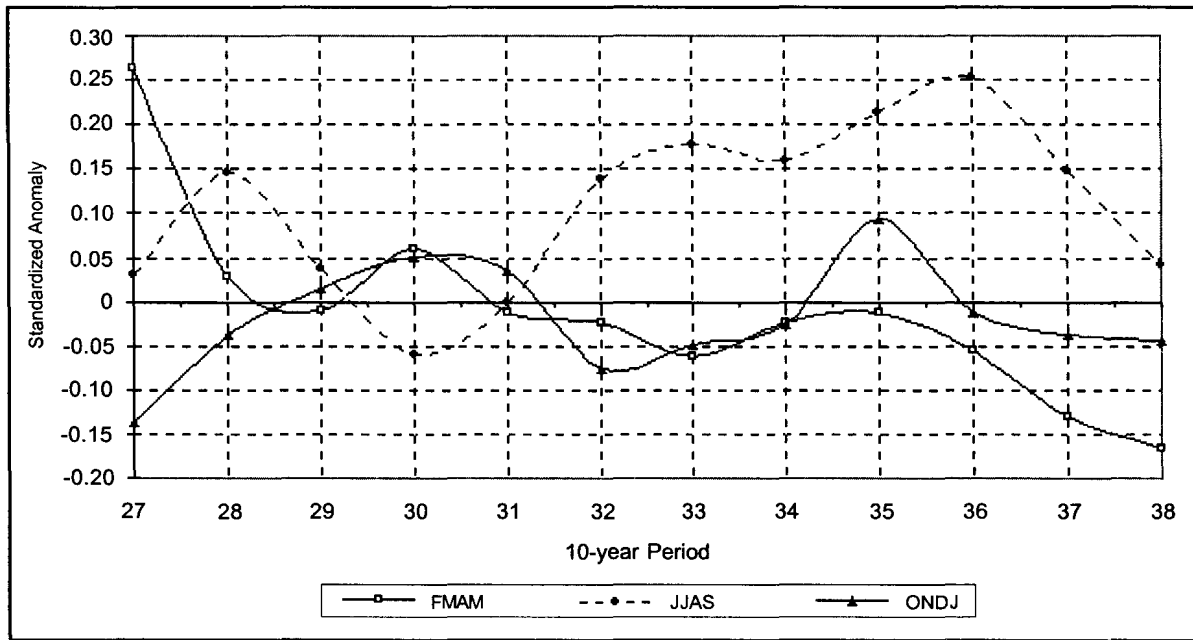The time series of RAI's computed from the 4-monthly rainfall totals suggest:

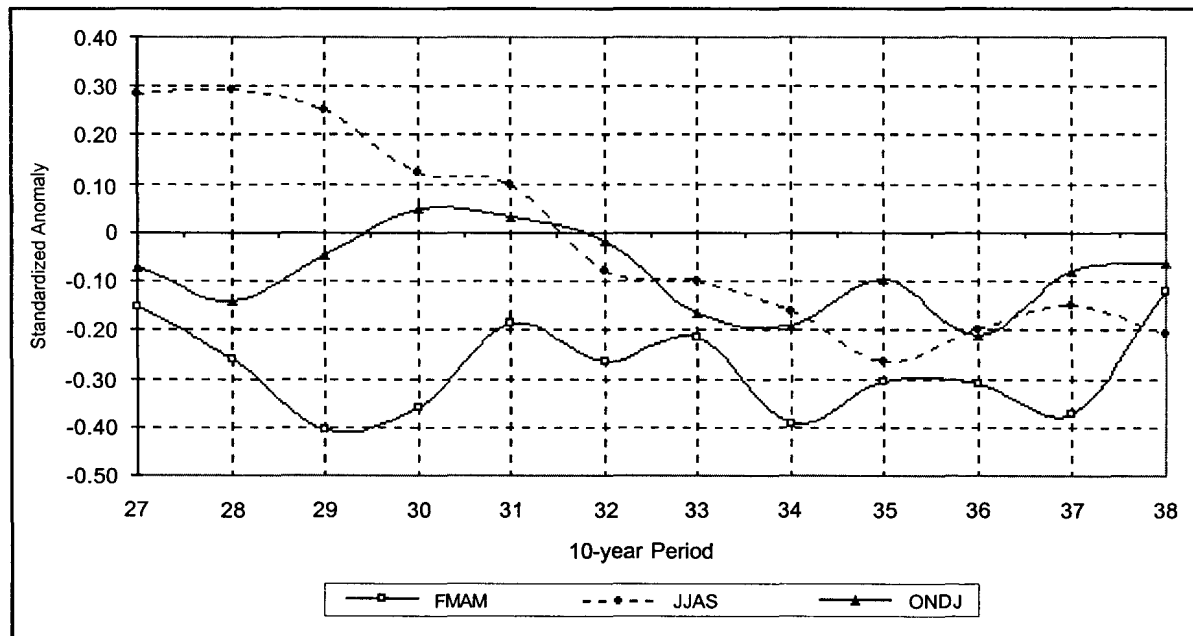Figure 6a. Ten-year moving average for type 1 climate.

Figure 6b. Ten-year moving average for type 2 climate.

(a) Rainfall may have changed over the period of study. Long periods (10Y-MA filtered RAI's) are indicative of a statistically significant falling rate over climate types 1, 2, & 5 but increasing rate over climate type 4 during the period February through May. Negative trend is also significant from October through January for climate type 4. The longer-period rainfall has significant falling rate for
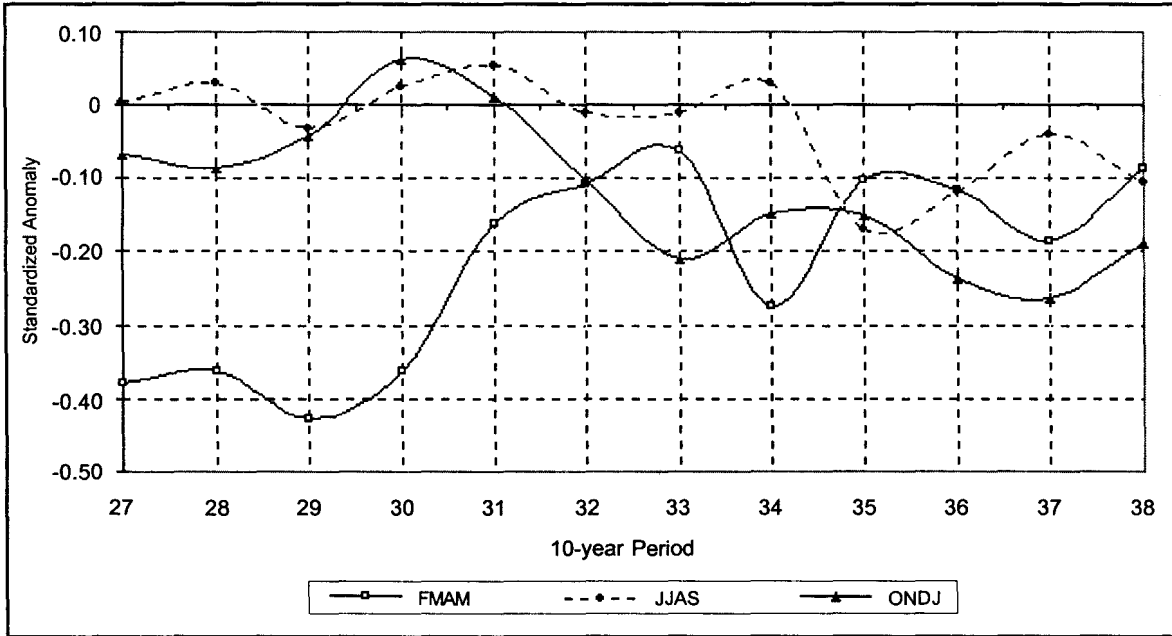
21

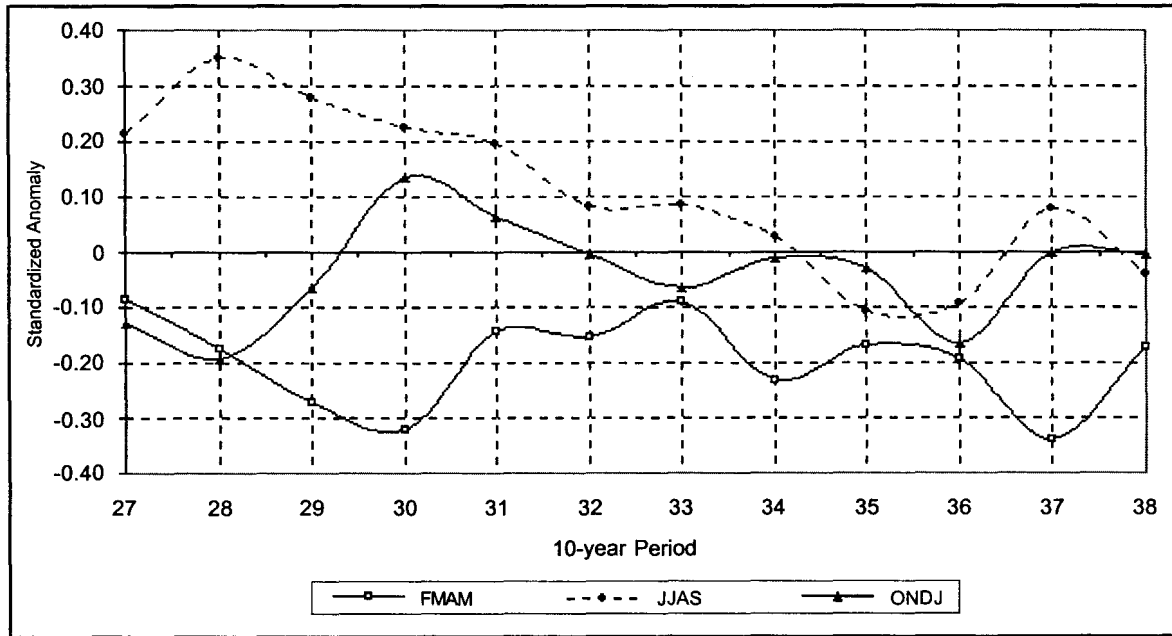Figure 6c. Ten-year moving average for type 3 climate.

Figure 6d. Ten-year moving average for type 4 climate.

climate types 2 & 4 but increasing rate for climate type 5. These trends also occurred during February through May.

(b) During the period of study, the La Niña event of 1975/76 (SD=3.0) gave the highest positive rainfall anomaly for all events. This occurred during the four-month period of February, March, April, and May in climate type 1 that includes Metro Manila.
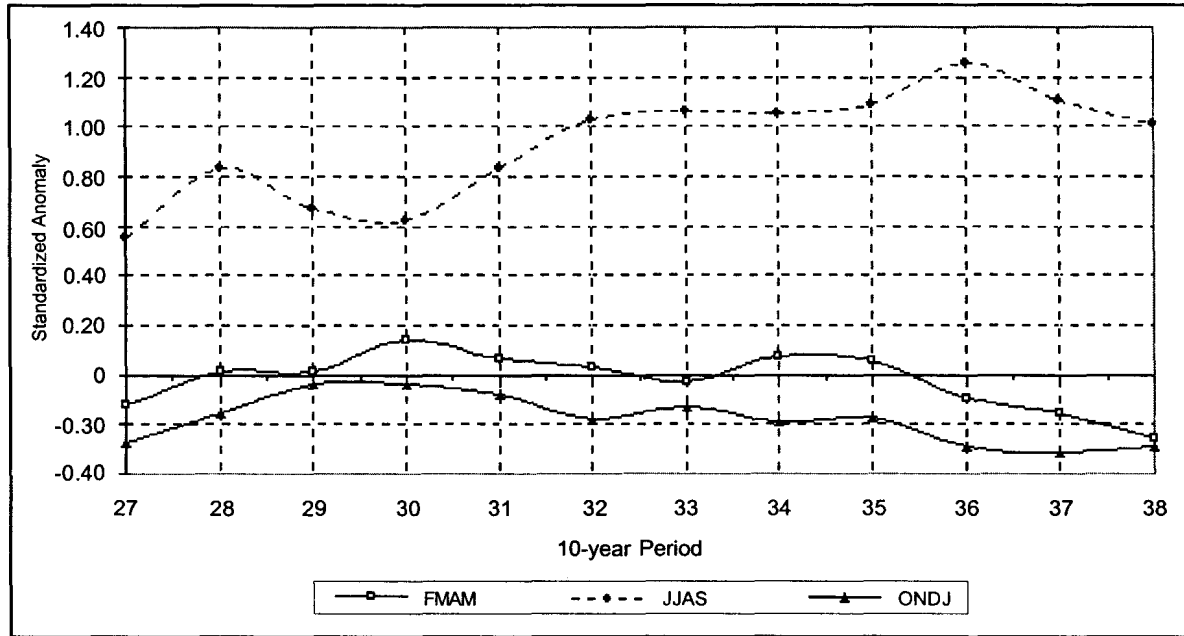
Figure 6e. Ten-year moving average for type 5 climate.

NOTE: Significant values are shaded.

Climate type	4-month season	SD	Z_1	Z_2	χ^2	V	r	t
1	FMAM	0.74	4.77	6.38	5.596	2.13	-0.01	0.23
	JJAS	0.66	2.05	1.98	6.277	1.90	0.12	0.001
	ONDJ	0.69	2.88	2.13	3.553	2.30	0.03	0.89
2	FMAM	0.81	1.64	0.75	5.936	2.25	-0.18	-1.37
	JJAS	0.63	0.56	-0.34	6.957	1.87	-0.01	0.21
	ONDJ	0.75	0.79	-0.56	1.170	2.37	-0.07	0.18
3	FMAM	0.79	-0.32	0.34	1.170	1.93	-0.15	-2.01
	JJAS	0.60	0.87	-0.12	2.191	2.23	-0.14	-0.45
	ONDJ	0.70	0.02	-1.58	6.277	2.23	-0.13	-0.38
4	FMAM	0.77	1.13	0.44	0.830	2.25	-0.13	-1.12
	JJAS	0.54	1.41	0.81	7.638	2.36	0.03	0.69
	ONDJ	0.75	0.63	-1.20	3.553	2.21	-0.03	0.45
5	FMAM	0.69	1.02	-0.70	10.362	2.23	0.02	0.15
	JJAS	0.88	0.98	-0.58	10.702	1.90	-0.004	-0.82
	ONDJ	0.89	0.80	1.01	4.234	2.09	-0.08	-0.46
Total statistic			1.96	1.96	11.07	2.52	0.198	1.96

Table 7. Descriptive statistics of the RAI (1950-1996).

However, the impact of each La Niña event on all climate types is not a definite positive rainfall anomaly except the 1964/65 event that registered positive anomalies for all climate types during the two successive four-month periods starting the last quarter of the La Niña year; during the four-month period of October, November, December, and January of 1956, 1964, 1970, 1971, 1973, 1974, 1989; and the four-month period of February, March, April, and May of 1996.
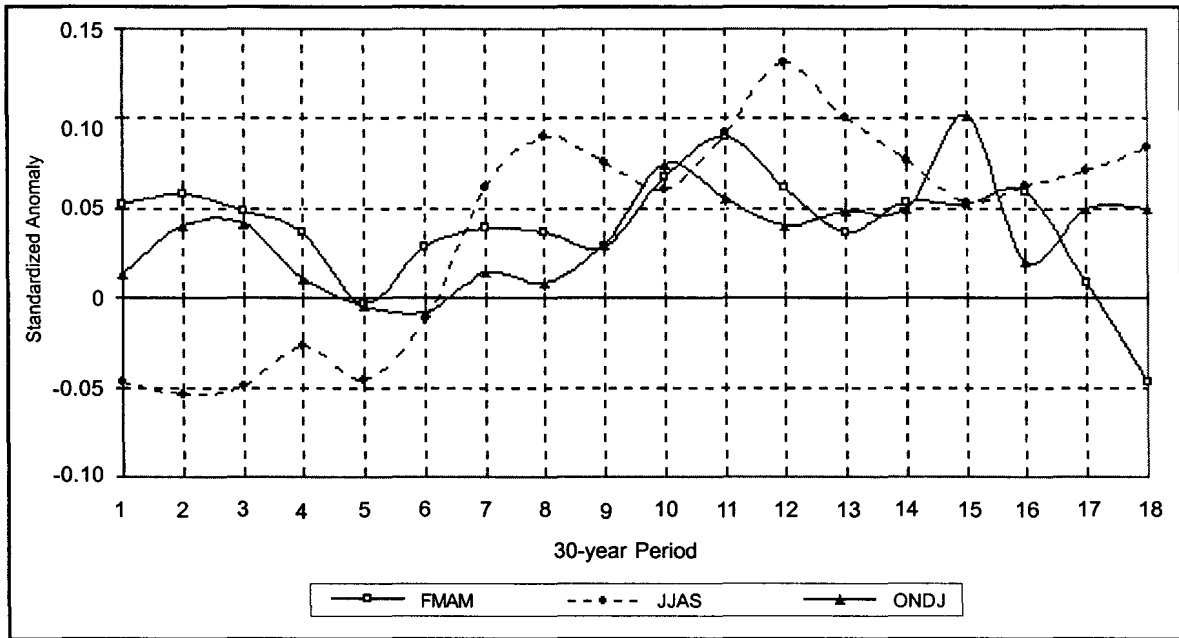
Figure 7a. 30-year moving average for type 1 climate.
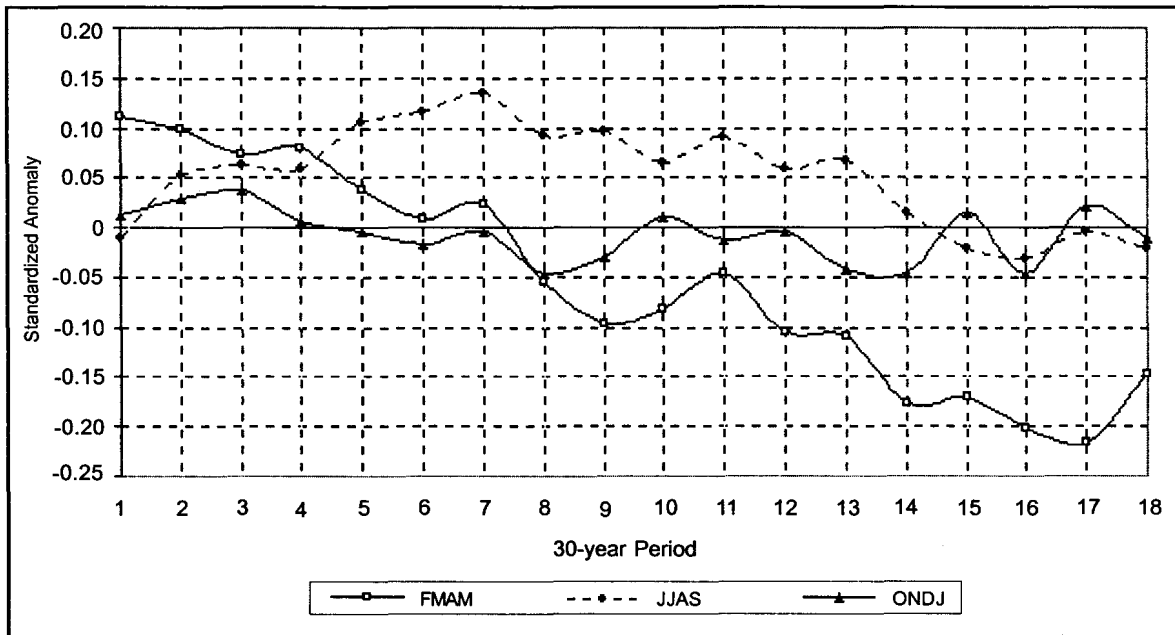

Figure 7b. 30-year moving average for type 2 climate.

(c) During the period of study, the El Niño of 1982/83 registered the lowest negative rainfall anomaly (SD = -2.0) for climate type 3 (central and western Visayas including most parts of Mindanao). However, the impact of each El Niño event on all climate types is not a definite negative rainfall anomaly except during the El Niño of 1972/73, 1982/83 and 1994/95 that registered negative rainfall anomalies for all climate types during two successive four-month periods starting the last quarter of the El Niño year.
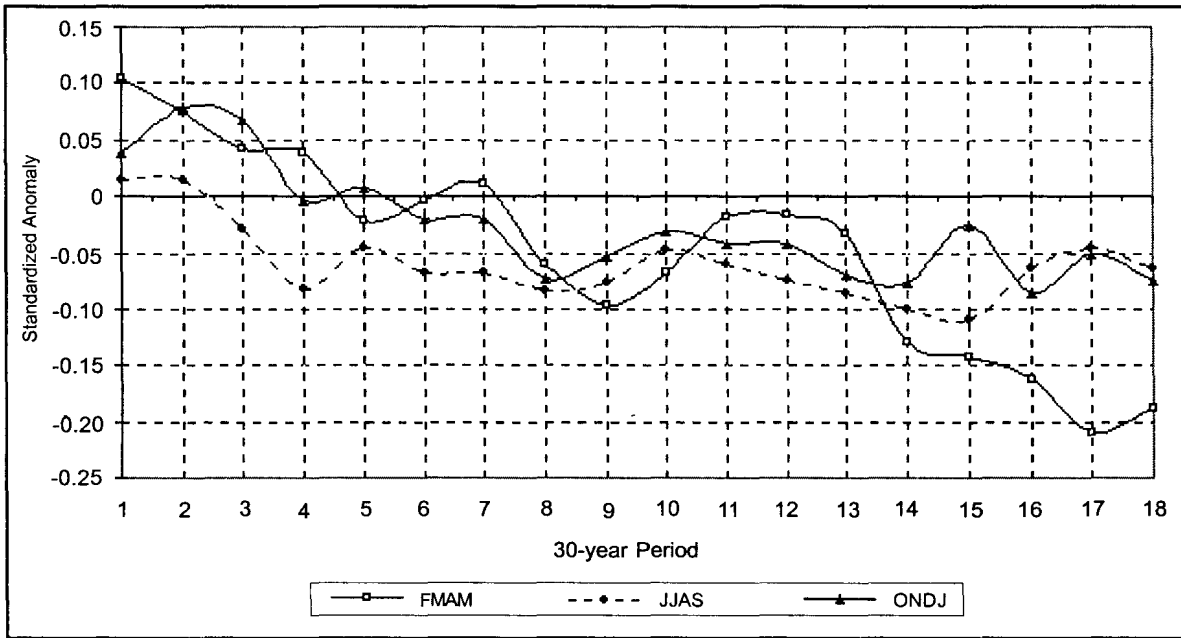
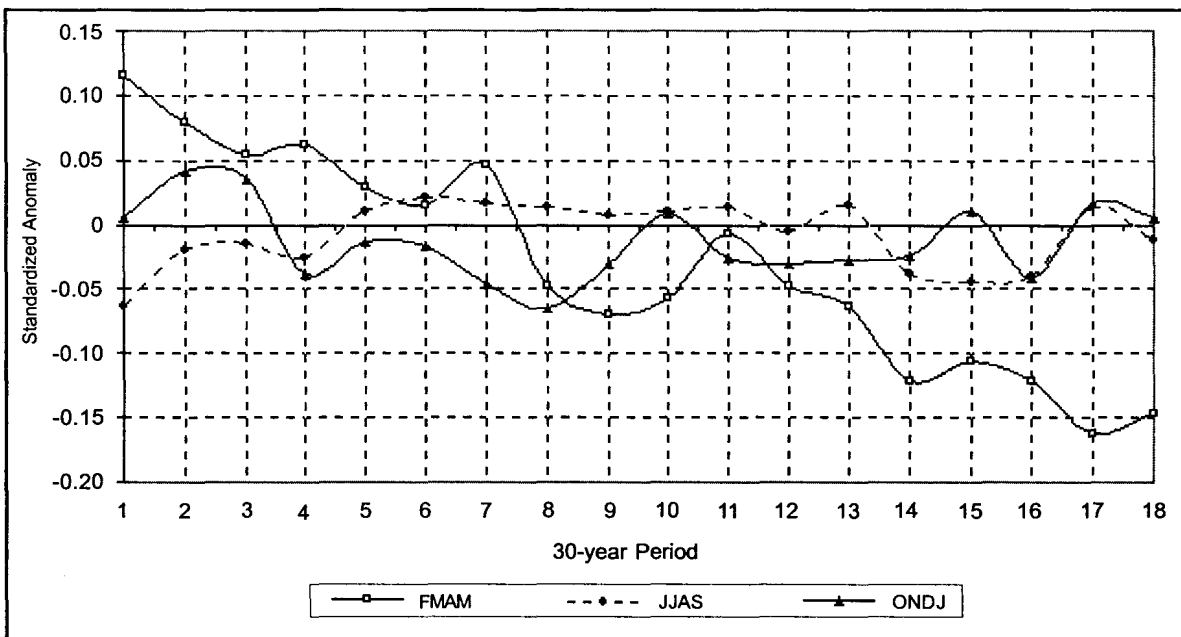Figure 7c. 30-year moving average for type 3 climate.

Figure 7d. 30-year moving average for type 4 climate.

ACKNOWLEDGMENTS
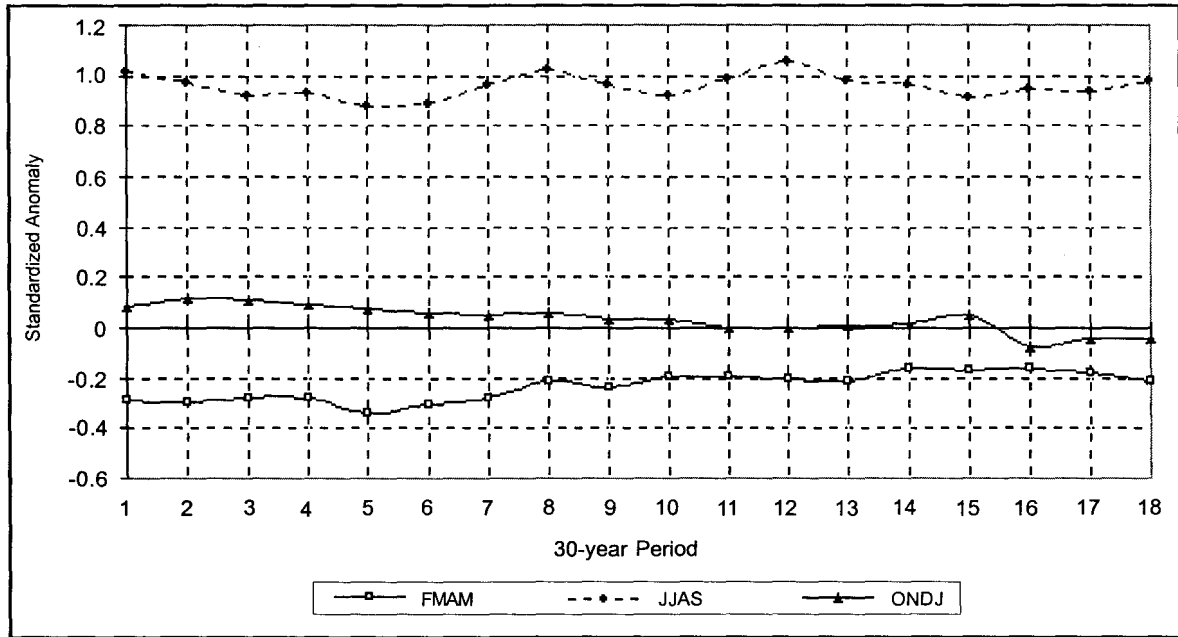
Figure 7e. 30-year moving average for type 5 climate.

Climate type	4-month season	SD	Z_1	Z_2	χ^2	V	τ	t
1	FMAM	0.25	0.22	-1.39	12.526	0.142	-0.49	-20.0
	JJAS	0.12	1.79	0.64	10.842	0.43	0.03	0.18
	ONDJ	0.13	0.97	0.08	1.579	0.45	-0.32	-0.08
2	FMAM	0.17	0.77	-1.16	8.737	0.27	-0.62	-3.33
	JJAS	0.15	0.19	0.11	5.789	0.34	0.09	1.40
	ONDJ	0.16	-2.30	-0.14	1.579	0.40	-0.001	-0.14
3	FMAM	0.12	0.87	0.05	12.947	0.49	-0.12	-0.15
	JJAS	0.17	-2.54	1.29	9.158	0.33	0.17	0.15
	ONDJ	0.16	18.36	-0.76	14.632	0.35	0.21	0.32
4	FMAM	0.19	-0.11	-0.86	10.842	0.39	0.38	4.33
	JJAS	0.24	-0.84	-0.62	9.579	-0.58	-0.14	-7.00
	ONDJ	0.22	0.92	-1.13	2.421	0.38	-0.36	-6.33
5	FMAM	0.23	0.82	-1.15	5.789	0.21	-0.56	-27.00
	JJAS	0.17	-0.15	-1.44	6.211	0.31	-0.03	-1.40
	ONDJ	0.15	0.20	-0.47	5.368	0.38	-0.12	-0.04
Total statistic			1.96	1.96	11.07	2.59	0.221	1.96

Table 7. Descriptive statistics of the 10-yr moving average filtered RAI.

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Climate type	4-month season	SD	Z_1	Z_2	χ^2	V	τ	t
1	FMAM	0.030	-7.76	36.52	11.33	2.14	-0.08	0.000
	JJAS	0.061	-9.56	-26.09	14.89	0.40	0.53	2.531
	ONDJ	0.028	11.26	57.07	5.11	1.95	0.37	-0.149
2	FMAM	0.108	-0.74	16.17	3.33	0.29	-0.86	-1.789
	JJAS	0.052	-11.76	28.70	15.78	0.71	-0.33	-0.462
	ONDJ	0.027	-7.10	22.95	3.33	2.38	-0.29	-0.033
3	FMAM	0.091	-7.35	153.91	2.44	0.50	-0.78	-0.438
	JJAS	0.034	7.26	49.13	6.89	107.00	-0.37	-0.260
	ONDJ	0.048	9.04	56.09	4.22	0.92	-0.67	-0.144
4	FMAM	0.084	-43.87	20.87	3.33	0.45	-0.84	-1.263
	JJAS	0.026	-8.88	252.94	15.78	1.19	-0.02	0.000
	ONDJ	0.029	-1.18	30.05	6.00	1.34	-0.00	0.000
5	FMAM	0.055	9.14	26.74	10.44	-0.31	0.62	6.429
	JJAS	0.045	-7.31	13.17	5.11	-0.26	0.06	0.714
	ONDJ	0.045	11.26	568.04	4.22	0.51	-0.75	-0.179
Total statistic			1.96	1.96	11.07	2.89	0.338	1.96

Table 9. Descriptive statistics of the 30-yr moving average filtered RAI.

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