CLIMATIC FLUCTUATIONS AND HOMOGENIZATION OF NORTHEAST BRAZIL USING PRECIPITATION DATA[1]

S. JEEVANANDA REDDY[2]

ABSTRACT - In order to assess the cyclic variations in the precipitation series and to homogenize the precipitation regimes of the Northeast Brazil 70-years annual precipitation data of 105-locations were subjected to power spectrum analysis. In terms of some cycles the regions above and below 8°S lat. differ significantly. Also regions between 4-8°S lat. are different in some respects from regions above 4°S lat. This is true with respect to coefficient of variation of annual precipitation. The auto-regression of Fortaleza data of 1849 to 1981 revealed the presence of four cycles, namely 52, 26, 13 and 6.5 years. The integrated curve of these four cycles is compared with the observed precipitation. The agreement in general is good with few exceptions. The same predicted curve is also used to compare with the observed precipitation at few other locations. The agreement is good only for few regions. The coefficient of variation of annual precipitation presented a non-homogeneity over regions above 8°S lat. compared to regions below 8°S lat. This is also true even with the observed cycles. This type of discrepancy is attributed to the non-homogeneity in the data series, which is also substantiated with few examples. This study demonstrates that the basic precipitation data must be corrected for homogeneity before they are actually used in the agricultural productivity estimates or planning strategies using regression approach.

Index tems: cycles, power spectrum.

FLUTUAÇÕES CLIMÁTICAS E HOMOGENEIZAÇÃO DO NORDESTE DO BRASIL UTILIZANDO DADOS DE PRECIPITAÇÃO

RESUMO - Objetivando conhecer a variação cíclica nas séries de precipitação e homogeneidade do regime pluviométrico do Nordeste do Brasil, dados de 70 anos de precipitação anual de 105 locais foram submetidos a análise do poder de espectro. Em termos de alguns ciclos as regiões acima e abaixo de 8° de latitude diferem significativamente. Também regiões entre 4-8° de latitude são diferentes em relação as regiões acima de 4° de latitude em alguns aspectos. Isto certamente também é correto com relação ao coeficiente de variação da precipitação anual. A auto-regressão dos dados de Fortaleza de 1849 a 1981 indica a presença de quatro ciclos, normalmente de 52, 26, 13 e 6,5 anos. A curva integrada deste quatro ciclos é comparada com a precipitação observada. A precisão em geral é boa, com poucas exceções. A mesma curva estimada é também usada para comparar com precipitações observadas em outros locais. A precisão é boa somente para poucas regiões. O coeficiente de variação da precipitação anual apresenta uma não-homogeneidade sobre regiões acima de 8° da latitude comparado a regiões abaixo de 8° de latitude. Isto certamente também é correto. Este tipo de discrepância é atribuído à não-homogeneidade da série de dados, a qual é também evidenciada com poucos exemplos. Este estudo demonstra que os dados básicos de precipitação deve ser corretamente homogeneizado, antes de ser utilizado em estimativa de produtividade agrícola ou estratégias de planejamento, utilizando métodos de regressão.

Termos para indexação: ciclos, poder de espectro.

INTRODUCTION

The objective of the wider study of which this paper is only one component is to divide the Northeast Brazil into Agronomically relevant zones in terms of crops/cropping pattern and land and water management practices. Traditional crops, varieties and croping systems often do not make full and efficient use of available soil and water resources. If the climate presents significant cyclic variation with time with alternative long dry and humid periods, the suggested new improved farming systems should be flexible according to these variations.

Among the several climatic parameters, the precipitation has close bearing on the agricultural productivity of a region in the tropics. Also, several climatic parameters are directly related to the precipitation over the Northeast Brazil; for example, potential evapotranspiration that defines the water need at a place (Reddy & Amorim 1984) and global solar radiation (Reddy et al. 1984).

1 Accepted for publication on March 7, 1984.
Presented at "III Congresso Brasileiro de Agrometeorologia" held at Instituto Agronômico de Campinas, SP, during 17 to 22 July 1983.

2 Consultant (Agroclimatology) EMBRAPA/IICA, Centro de Pesquisa Agropecuária do Trópico Semi-Árido (CPATSA), Caixa Postal 23, CEP 56300 Petrolina, PE, Brazil.

Therefore, the study of cyclic variation in the precipitation is very important in the tropics for appropriate long term planning of agriculture.

In the past some efforts have been made to understand the cyclic variations in the precipitation of the Northeast Brazil (Strang 1979, Girardi 1983, Carlos et al. 1982). Majority of these studies used Fortaleza data series only. However, the precipitation patterns in terms of seasonal variation and commencement of humid period present high variations with latitude and longitude over the Northeast Brazil (Reddy & Amorim 1983).

Therefore, the specific objective of this study is to identify periodicities in the long series of precipitation data over different parts of the Northeast Brazil and homogenize the precipitation regimes according to identified cycles and point out the non-homogeneity in the precipitation series of the Northeast Brazil. For this study 70-years annual precipitation data of 105-locations over the Northeast Brazil (excluding Maranhão and Piauí) were used.

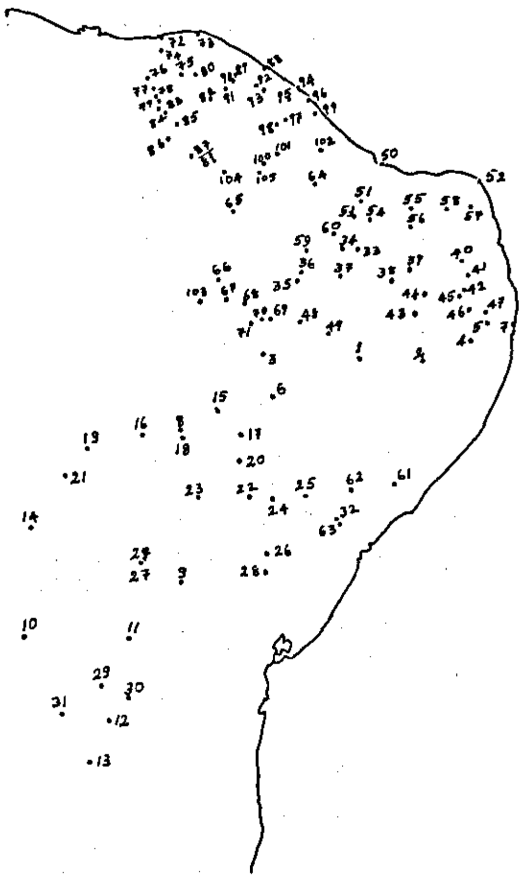

FIG. 1. List of locations.

MATERIAL AND METHODS

The basic data consists of 70-year annual precipitation for the duration of 1912-1981 for about 105 locations over Northeast Brazil (Fig. 1 and Table 1). The data were supplied by the SUDENE (Recife). If only one or two-month data were missing, then these were filled with the average monthly values. In the case of Fortaleza, the data are from 1849 to 1981.

The annual precipitation data were subjected to power spectrum analysis of Blackman & Tukey (1958) as presented in World Meteorological Organization (1966) technical note no. 77. To achieve satisfactory resolution in the spectrum a maximum lag of 25 was chosen. The spectral estimates were smoothed by "Hanning method" with weights 0.23, 0.54 and 0.23. The spectra exhibit many peaks and troughs. To test whether these peaks are accidental due to sampling effects or the series indicate any significant tendency to oscillate, the sampling theory of Tukey (1950) was used. The null hypothesis for this purpose are considered in accordance with the fact that the series revealed any persistency or not. If the persistence is of the "Markov linear type", the appropriate red-noise spectrum and the associated 99, 95 and 90% limits were calculated and the individual peaks were tested with reference to these limits. If the lag 1 correlation was significantly greater in magnitude than zero but higher lag correlations did not taper off exponentially, the spectral estimates in the first half was tested with reference to the red-noise spectrum and the rest against white noise. In the absence of any persistency, the spectral estimates were tested against white-noise spectrum. Out of 105 locations 47 presented persistence. Such bands can cause errors in the spectral estimates where there is less power (Jenkins & Watts 1968). It may be advantageous to filter the data digitally in order to improve the estimates at these frequencies. In the present study the time series represent only 70 values. It is, therefore, not attempted to filter the data series using either "Band pass filter" or "difference filter", as this process reduces the number of data points available for spectrum analysis. Also, there is no difference between the pattern of spectrum either with red-noise or white-noise.

RESULTS

Table 2 presents the significant cycles at the 105 locations over Northeast Brazil. In this table the numbers 1, 2 and 3 respectively stand for the 90, 95 and 99% levels of significance. The periods or cycles (in years) that correspond to different harmonics along with the class interval are presented in Table 3. Table 3 also presents the number

TABLE 1. List of locations used in the analysis.

Numbers	Name	Stage	Latitude o	Latitude '	Longitude o	Longitude '	Altitude (m)
1	Sertãnia	Pernambuco	08	05	37	16	605
2	Brejo da Madre de Deus	Pernambuco	08	09	36	23	646
3	Salgueiro	Pernambuco	08	04	39	07	415
4	Bom Jardim	Pernambuco	07	48	35	35	325
5	Timbaúba	Pernambuco	07	31	35	19	190
6	Belém de S. Francisco	Pernambuco	08	46	38	58	305
7	També	Pernambuco	09	23	40	30	376
8	Petrolina	Pernambuco	09	23	40	30	376
9	Mundo Novo	Bahia	11	51	40	28	480
10	Paratinga	Bahia	12	42	43	10	420
11	Andaraí	Bahia	12	49	41	20	386
12	Brumado	Bahia	14	12	41	40	457
13	Condeúba	Bahia	14	52	41	59	695
14	Barra	Bahia	11	05	43	09	410
15	Curaçá	Bahia	08	59	39	54	341
16	Casa Nova	Bahia	09	24	41	08	380
17	Patamuté	Bahia	09	25	39	29	400
18	Juazeiro	Bahia	09	25	40	30	371
19	Remanso	Bahia	09	41	42	04	378
20	Uauá	Bahia	09	50	39	29	439
21	Pilão Arcado	Bahia	10	10	42	26	-
22	Monte Santo	Bahia	10	26	39	20	489
23	Senhor do Bonfim	Bahia	10	27	40	11	544
24	Euclides da Cunha	Bahia	10	30	39	01	523
25	Cícero Dantas	Bahia	10	36	38	22	420
26	Araci	Bahia	11	20	38	57	212
27	Morro do Chapéu	Bahia	11	32	41	08	1012
28	Serrinha	Bahia	11	39	39	00	377
29	Rio de Contas	Bahia	13	34	41	49	1002
30	Ituaçu	Bahia	13	49	41	18	527
31	Caetité	Bahia	14	04	42	29	826
32	Paripiranga	Bahia	10	41	37	51	430
33	Brejo do Cruz	Paraíba	06	21	37	30	190
34	Catolé do Rocha	Paraíba	06	21	37	45	250
35	Cajazeiras	Paraíba	06	53	38	34	291
36	Antenor Navarro	Paraíba	06	44	38	27	240
37	Pombal	Paraíba	06	46	37	49	178
38	Santa Luzia	Paraíba	06	52	36	56	290
39	Picuí	Paraíba	06	31	36	22	450
40	Araruna	Paraíba	06	31	35	44	580
41	Bananeiras	Paraíba	06	46	35	38	552
42	Areia	Paraíba	06	58	35	42	445
43	S. João do Cariri	Paraíba	07	24	36	32	445
44	Soledade	Paraíba	07	04	36	22	560
45	Alagoa Nova	Paraíba	07	04	35	47	500
46	Ingá	Paraíba	07	17	35	37	144
47	Itabaiana	Paraíba	07	20	35	20	45
48	Conceição	Paraíba	07	33	38	31	370
49	Princesa Isabel	Paraíba	07	44	38	01	660
50	Areia Branca	Rio G. do Norte	04	51	37	08	5
51	Gov. Dix-Sept Rosado	Rio G. do Norte	05	28	37	31	36
52	Touros	Rio G. do Norte	05	12	35	28	4

TABLE 1. Continuation.

Numbers	Name	Stage	Latitude o	Latitude '	Longitude o	Longitude '	Altitude (m)
53	Caraúbas	Rio G. do Norte	05	47	37	34	146
54	Augusto Severo	Rio G. do Norte	05	51	37	19	65
55	Angicos	Rio G. do Norte	05	40	36	36	109
56	Santana do Matos	Rio G. do Norte	05	58	36	39	140
57	Taipu	Rio G. do Norte	05	37	35	36	50
58	Jardim de Angicos	Rio G. do Norte	05	39	36	00	150
59	Luis Gomes	Rio G. do Norte	06	25	38	24	640
60	Martins	Rio G. do Norte	06	05	37	55	645
61	Porto Real do Colégio	Alagoas	10	11	36	50	30
62	Nossa Senhora da Glória	Sergipe	10	13	37	27	290
63	Simões Dias	Sergipe	10	44	37	48	283
64	S.J. do Jaguaribe	Ceará	05	17	38	16	60
65	Mombaça	Ceará	05	45	39	38	223
66	Assaré	Ceará	06	52	39	52	435
67	Santana do Cariri	Ceará	07	11	39	44	480
68	Crato	Ceará	07	13	39	23	421
69	Brejo Santo	Ceará	07	29	38	59	490
70	Porteiras	Ceará	07	31	39	08	520
71	Jardim	Ceará	07	35	39	17	630
72	Camocim	Ceará	02	54	40	50	5
73	Acaraú	Ceará	02	53	40	07	7
74	Granja	Ceará	03	07	40	50	9
75	Meruoca	Ceará	03	27	40	29	450
76	Viçosa do Ceará	Ceará	03	34	41	05	685
77	Tianguá	Ceará	03	44	40	59	795
78	Ubajara	Ceará	03	51	40	56	870
79	Ibiapina	Ceará	03	55	40	53	885
80	Ipaguassu	Ceará	03	30	40	16	75
81	Tamboril	Ceará	04	50	40	20	360
82	Aracatiaçu	Ceará	03	53	40	02	190
83	S. Benedito	Ceará	04	03	40	52	903
84	Guaraciaba do Norte	Ceará	04	11	40	45	380
85	Bonito	Ceará	04	21	40	36	170
86	Ipueiras	Ceará	04	33	40	43	238
87	Tamboril	Ceará	04	50	40	20	360
88	Paracuru	Ceará	03	23	39	05	10
89	Itapipoca	Ceará	03	30	39	35	98
90	Itapagé	Ceará	03	41	39	35	280
91	Irauçuba	Ceará	03	44	39	47	190
92	S. Luiz do Curu	Ceará	03	40	39	14	35
93	Caucaia	Ceará	03	44	38	39	32
94	Fortaleza (Central)	Ceará	03	44	38	32	26
95	Maranguape	Ceará	03	53	38	41	67
96	Aquariz	Ceará	03	54	38	23	30
97	Acarape	Ceará	04	13	38	43	76
98	Baturité	Ceará	04	20	38	53	123
99	Cascavel	Ceará	04	08	38	14	30
100	Cedro	Ceará	04	58	39	04	190
101	Caio Prado	Ceará	04	39	38	58	111
102	Santa Antônio de Russas	Ceará	04	50	38	10	40
103	Araripe	Ceará	07	13	40	08	605
104	Boa Viagem	Ceará	05	08	39	44	235
105	Uruquê	Ceará	05	09	39	10	214

TABLE 2. Significant cycles in annual precipitation of 105 locations over northeast Brazil.

Location numbers	Mean* CV	Harmonic**																								
		0⁺	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
73	1123/49		1		2	3																					
72	1030/42	2				2	2						2	1													
74	1013/40					2	2				1	1	3	2													
75	1606/38	1	1	2	2												1										
76	1328/33					3	2						1	1		1	1										
80	881/40										3	3	3	2													
89	1115/37	2				1										1											
88	1223/43	3	3			1	1						2														
90	793/39	1	2	2										1													
91	531/45			1							1	2	2														
92	1007/49				3	3	2																				
94	1396/36	3	2			2																					
77	1196/35					2	3	1			3	1	1	1													
78	1463/34	1				3	3				2	1	2	2													
79	1626/48					2	2				2		1	1													
82	636/41	2		1						1	3	2	1			1											
93	1232/35	3	2			1																					
95	1369/37	3	2			1																					
83	1962/36	3	3					1																			
84	1257/43	2	1	3	2	2	1				1		2	3	1												
85	887/40					1	2				1						1										
96	1365/40	3	3	1												1											
99	1294/41					3	2																				
97	1065/36	3	2			1	1																				
98	1078/33			1									2	2													
86	923/41					2											1										
87	682/49					3	2				1						1										
81	682/49					3	2				1						1										
100	816/37					2							1	2	1												
101	805/38					1					1	1	1				3										
102	747/42	3				3	2				3	2		2	2	1											
105	721/44		1	1		2	1										2										
104	704/43	3		2	2	3	2					1	2	1													
64	744/42			1		2	2				2																
50	598/54					3	2																				
52	1015/33	1	3	2																							

TABLE 2. Continuation.

Location numbers	Mean* CV	Harmonic**																								
		0+	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
51	734/42					3										-											
65	806/41		1													-	-									-	1
53	651/42		-	-	1	3								1													
54	754/47		2	1		1																					
55	534/49		2	2		2	2									1	2										
58	520/49		1	2			1										2	1								1	
57	791/49		3	2	1												1										
60	1099/36	2				2	2										2	2									
56	719/48					2	2									1											
34	839/41	2	1			3	1																				
33	821/37	3				2					2			2	3												
59	907/31					-							1	2	1	1	1										
40	847/36		-	-	-											2	1										
41	1196/26											1	2														
66	677/34	2	2			2	2							1													
36	977/38	1		2	1						1			1	1												
35	867/33			-							1						1										
39	354/50	1	2	2		3	2								1	2	2										
37	728/34					2	2	1							1	-											
38	539/45					3	2										-							-			
42	1356/22	2	1								2	2															
45	1280/44	2	3	3																1							
44	386/46			2		1										1										2	2
67	951/44		2	2						1				1	1												
46	658/34	1	3																				-				
47	773/33		1	1																		1	2			1	
68	1098/29			-	2	2		1	1																		
69	896/32			0	2						1				1												
43	391/45	2				2	2				1	1									2						
5	1034/25		2																								
7	1367/21		2				2	1				1	2									1					
70	904/31			3	1										1		1										
71	795/34			2	2	3	3								2	1	2										
48	864/51	3	3	2										2	3	1											
49	805/33			3	1					1					1												
4	1567/59	3	3	3																							

TABLE 2. Continuation.

Location numbers	Mean* CV	Harmonic**																									
		0⁺	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
3	587/34					1	1																				
1	539/36		1	2	2	2																					
2	848/26			1			1																				
6	435/44					-																					
15	452/38			-													1										
8	425/41		1	3	2	1										1	3										
17	357/70		1	3	3																						
19	568/32			-											2												
16	488/39	3				3	3	1						2	2	1	1				2	1	1	2			
18	456/41		-	-																	1	1					
20	492/49	1	1	2																							1
61	899/27													2	1											2	
21	655/28			2																		1	1				
62	701/33		3	3	1																						
23	842/30	1	-	-																							1
22	659/35			1																					-	-	
24	713/35	2	-																								
25	875/32			-																							
32	914/37	-	3	3																							
63	870/29	3		2	1	2										1	1										
14	760/28					1	2																		2	1	
103	630/44		3	3	1										1		1										
26	665/35	2	3	3																-	1						
27	716/30	3	2	2														-									
28	852/26			2	1														1								
9	1021/38		2	2			2																				
10	757/28	2	1				-				1	1															
11	1125/35			2																		1	2				
29	852/37		2	3	1																						
30	684/37																						-				
12	657/31	1		1							2											1	2	1			
31	854/28					2	1																2	1		2	1
13	743/29						1																-			-	

⁺ Locations with persistence
- significant just at 90% level
* mean annual precipitation/coefficient of variation
** significant at: 1-90%; 2-95%; and 3-99%.

TABLE 3. Harmonics and the corresponding periods*.

Harmonic numbers	Significant number of locations (%)	Period (class interval) (years)
0	38 (36.2)	999.99 (1000.0 - 100.0)
1	41 (39.0)	50.00 (100.0 - 33.3)
2	45 (42.9)	25.00 (33.3 - 20.0)
3	21 (20.0)	16.67 (20.0 - 14.3)
4	50 (47.6)	12.50 (14.3 - 11.1)
5	38 (36.2)	10.00 (11.1 - 9.1)
6	6 (05.7)	8.33 (9.1 - 7.7)
7	1 (01.0)	7.14 (7.7 - 6.7)
8	4 (03.8)	6.25 (6.7 - 5.9)
9	21 (20.0)	5.56 (5.9 - 5.3)
10	14 (13.3)	5.00 (5.3 - 4.8)
11	18 (17.1)	4.55 (4.8 - 4.3)
12	23 (21.9)	4.17 (4.3 - 4.0)
13	17 (16.2)	3.85 (4.0 - 3.7)
14	16 (15.2)	3.57 (3.7 - 3.4)
15	23 (21.9)	3.33 (3.4 - 3.2)
16	2 (01.9)	3.13 (3.2 - 3.0)
17	1 (01.0)	2.94 (3.0 - 2.9)
18	0 (00.0)	2.78 (2.9 - 2.7)
19	5 (04.8)	2.63 (2.7 - 2.6)
20	7 (06.7)	2.50 (2.6 - 2.4)
21	7 (06.7)	2.38 (2.4 - 2.3)
22	4 (03.8)	2.27 (2.3 - 2.2)
23	2 (01.9)	2.17 (2.2 - 2.1)
24	7 (06.7)	2.08 (2.1 - 2.0)
25	3 (02.9)	2.00 (2.0 - 2.0)

* data points = 70 and lags = 25

of locations (in percent) are significant out of the 105 locations in different harmonics.

Harmonics 0, 1, 2 and 4-5 are significant at more than 35% of locations (Table 3). Harmonics 9-15 and 3 are significant at more than 10% of locations. The band 9-12 harmonics are more confined to northwestern parts; while the band 12-15 harmonics are more confined to central parts. The very high harmonics (16-25) are more confined to southern parts. The persistence and the harmonics '0' and '1' are more confined to regions above 10°S latitude, while the harmonic '2' is significant at many locations below 5°S lat[3]. The harmonics 4-5 are significant at locations above 10°S lat.

[3] Here above and below certain value of latitude refer to towards the equator and towards south pole respectively.

Fig. 2 depicts the mean annual precipitation and its coefficient of variations (CV) at 105 locations. The CV's are uniformly lower in South Bahia State. The CV's are irregular over 4-8°S lat. belt.

Fig. 3-7 depict the detailed spectrum results at few selected locations. The data series present white-noise at Fortaleza and Taipu red-noise at the other three locations. In all these diagrams the significant levels (90, 95 and 99%) represent that of white-noise. In fact, the significant levels for red-noise decrease exponentially from 0 harmonic with incresing harmonics. Hence, at Conceição and Rio de Contas, respectivelly, the peaks at harmonics 24, 15 and 44, which are not statistically significant according to white-noise levels, are significant at red-noise levels. At Fortaleza, in addition to 0, 1, 2 harmonics, 4 is also significant. At Itabaiana, hamonics 1, 2, 20 and 25 are significant. At Taipu,

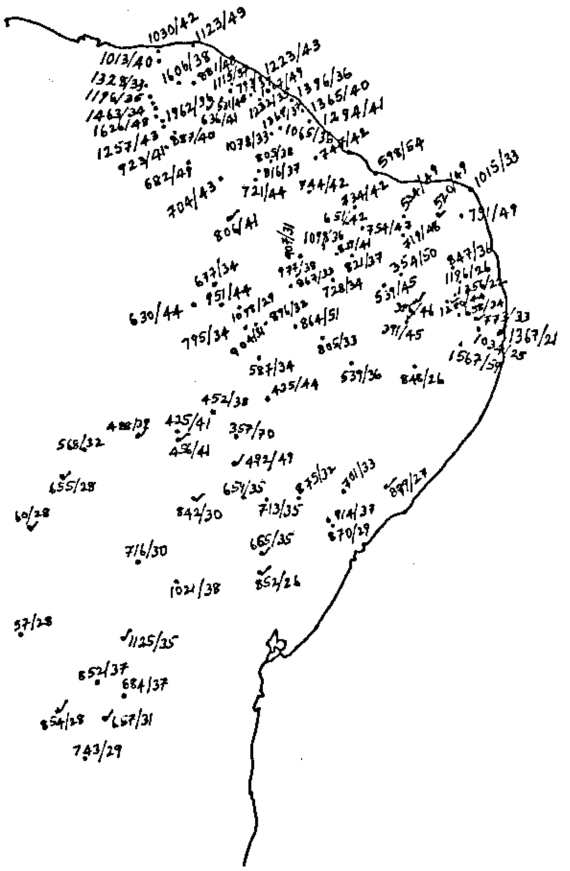

FIG. 2. Locations at which harmonics '16-25' are significant (v) and mean annual precipitation and its C.V.

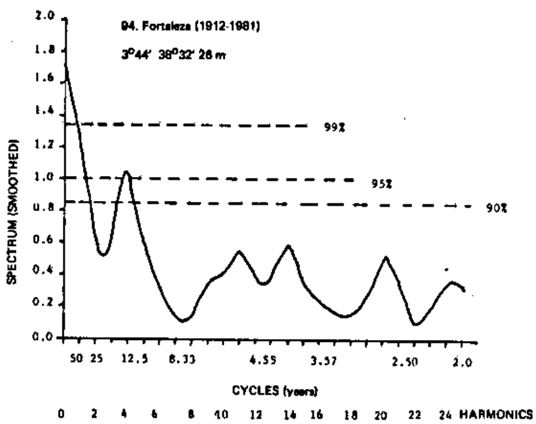

FIG. 3. Spectrum results of Fortaleza (Ceará) precipitation data.

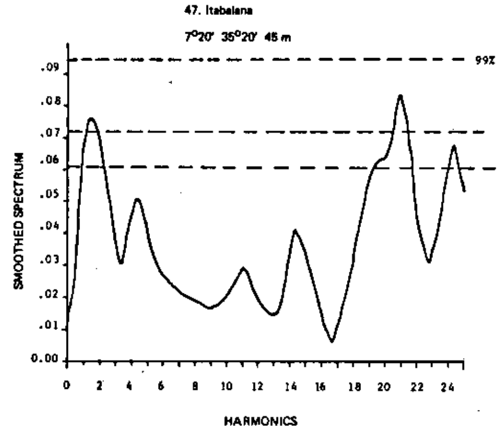

FIG. 4. Spectrum results of Itabaiana (Paraíba) precipitation data.

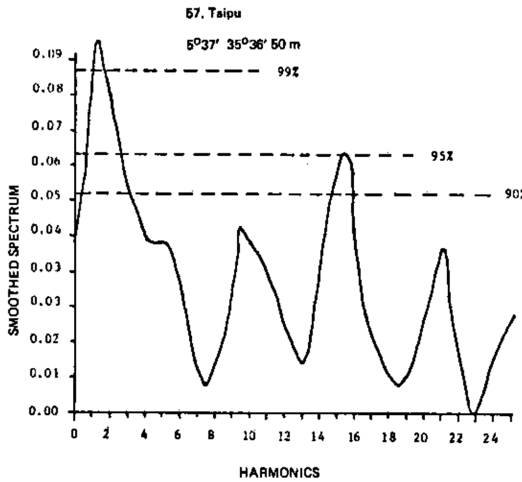

FIG. 5. Spectrum results of Taipu (Rio Grande do Norte) precipitation data.

hamonics 1, 2, 3 and 15 are significant. At Conceição, the harmonics 0, 1, 2, 13 and 24 are significant while at Rio de Contas harmonics 1, 2, 15 and 21 are significant.

Fig. 8-13 depict the time series of precipitation expressed as the ratio of average precipitation i.e. $P_i' = [(P_i - \bar{P})/\bar{P}]$, where P_i is the precipitation of year i, and $\bar{P}$ is the average precipitation of the series at few select locations. These series are compared with the predicted curve estimated as follows:

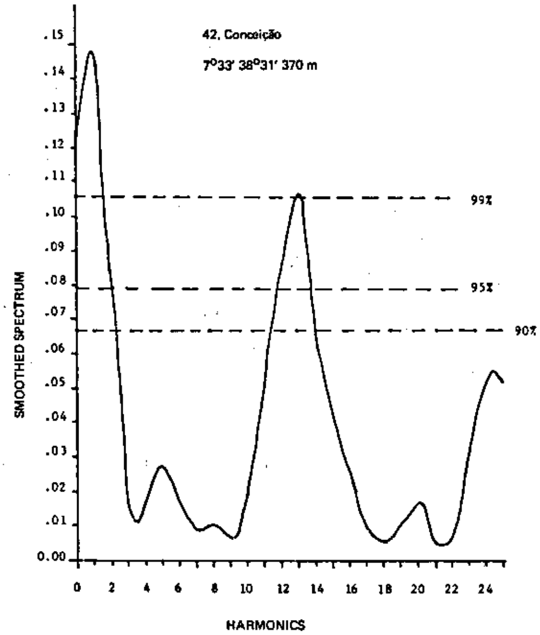

FIG. 6. Spectrum results of Conceição (Paraíba) precipitation data.

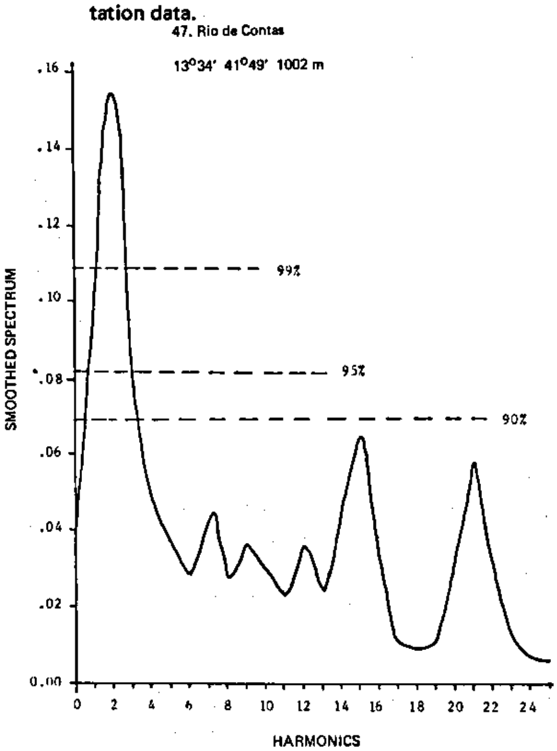

FIG. 7. Spectrum results of Rio de Contas (Bahia) precipitation data.

From the long-period (133-years) annual precipitation series during 1849-1981 of Fortaleza the P'_i values are computed and subjected to auto--regression analysis. This analysis revealed cycles of 52, 26, 13 and 6.5 years as significant. These four cycles can be integrated through trignometric function of the form:

$$\hat{P}'_i = \sum_{j=1}^{4} A_j \,\mathrm{Sin} \left| \frac{2\Lambda i}{T_j} + \phi_j \right|$$

were A_j, ϕ_j and T_j respectively stand for amplitude, phase angle and period of the cycle j; and i = 1, 2, 3 . . . in wich 1, 2, 3 . . . stand for consecutive years with ϕ_j representing at i = 0 year.

The values A_j and ϕ_j are obtained through iterative regression analysis and are presented in Table 4. For the four cycles the phase angles are different while the amplitudes (normalized) of cycles 1 is same as 4 and 2 is same as 3 with the amplitude of cycles 2 and 3 is greater than 1 and 4.

Using the data set of Table 4 in the above equation, the predicted curve ($\hat{P}'_i$) is estimated with the base year as 1911 (i = 0) and are depicted in Fig. 8-13 in the case of Fig. 8-11, the predicted curves are shifted by 3-years.

The agreement between observed (P'_i) and predicted ($\hat{P}'_i$) values is good with few exceptions for Fortaleza (Fig. 13) and for Rio Grande do Norte (average of 12-locations) (Fig. 12). The agreement is poor for locations in Bahia State (Paratinga and Condeuba - Fig. 8), for Porto Real do Colégio (Alagoas - Fig. 9) and També (Pernambuco - Fig. 10).

At many locations the rainfall pattern presents below average pattern during 1920-1960 for about 35 years with few exceptions Petrolina (Fig. 10), Touras (Fig. 9), També (Fig. 10), Ipeucas (Fig. 11). By shifting the i = o year from 1911 to 1914, the agreement between observed and predicted curves are good for years before 1920's and after 1955's at Petrolina, Touras etc.; and without this shift it agrees more or less in the case of Sta. Luzia (Fig. 11) and Ipeucas (Fig. 11).

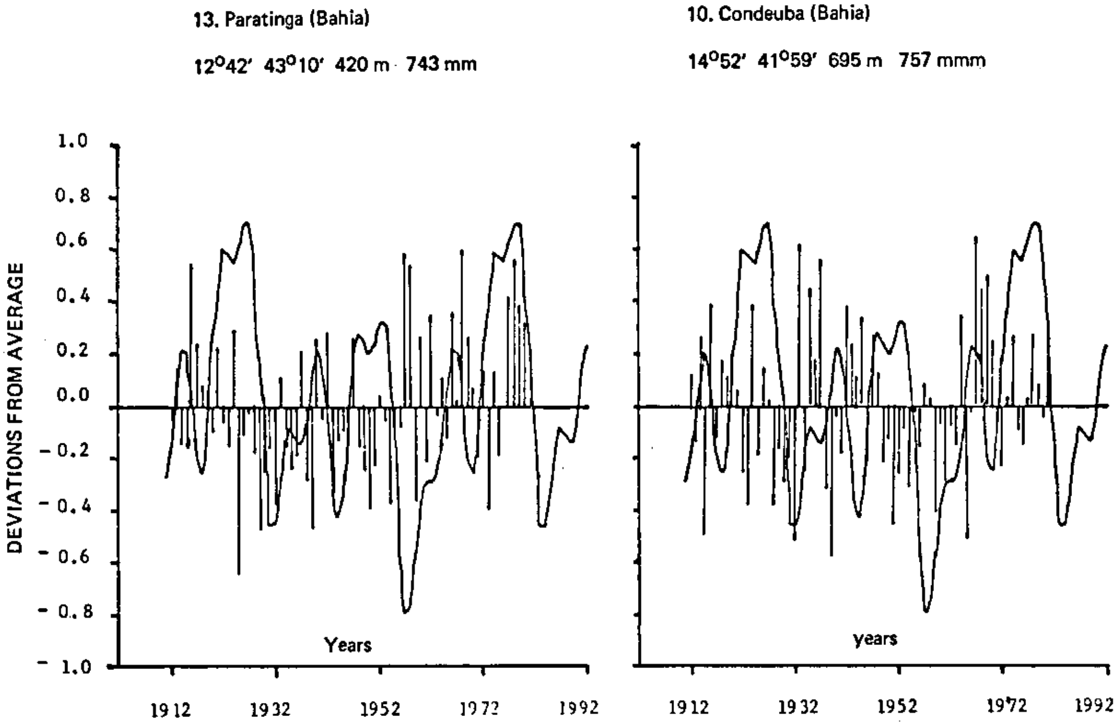

FIG. 8. Time series of Paratinga and Condeuba precipitation.

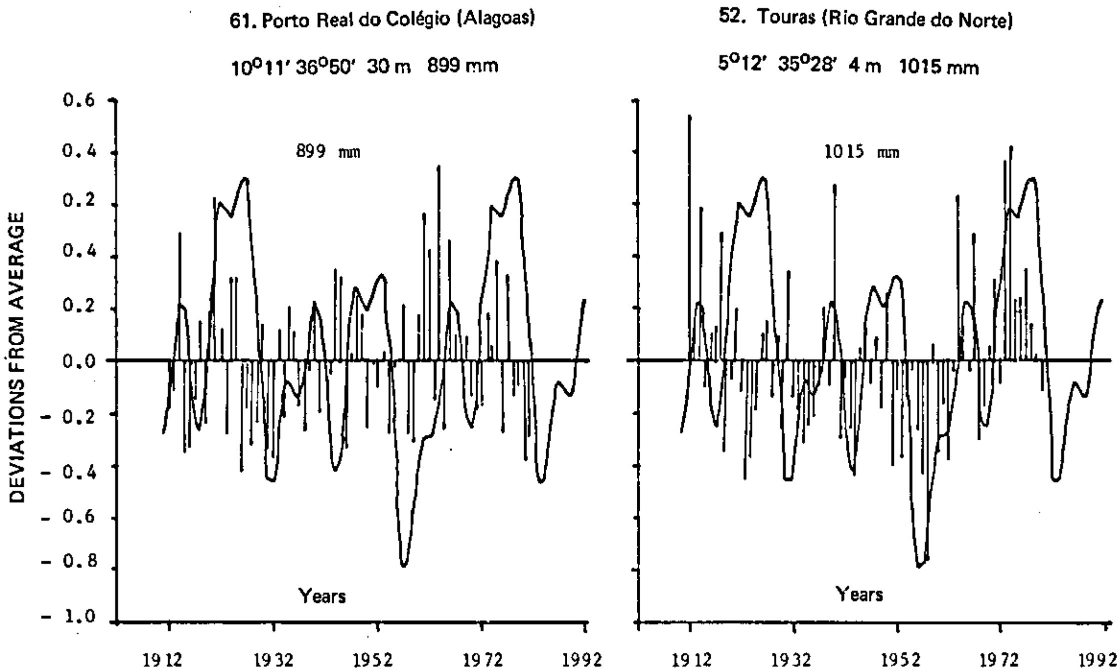

FIG. 9. Time series of Porto Real do Colégio and Touras precipitation.

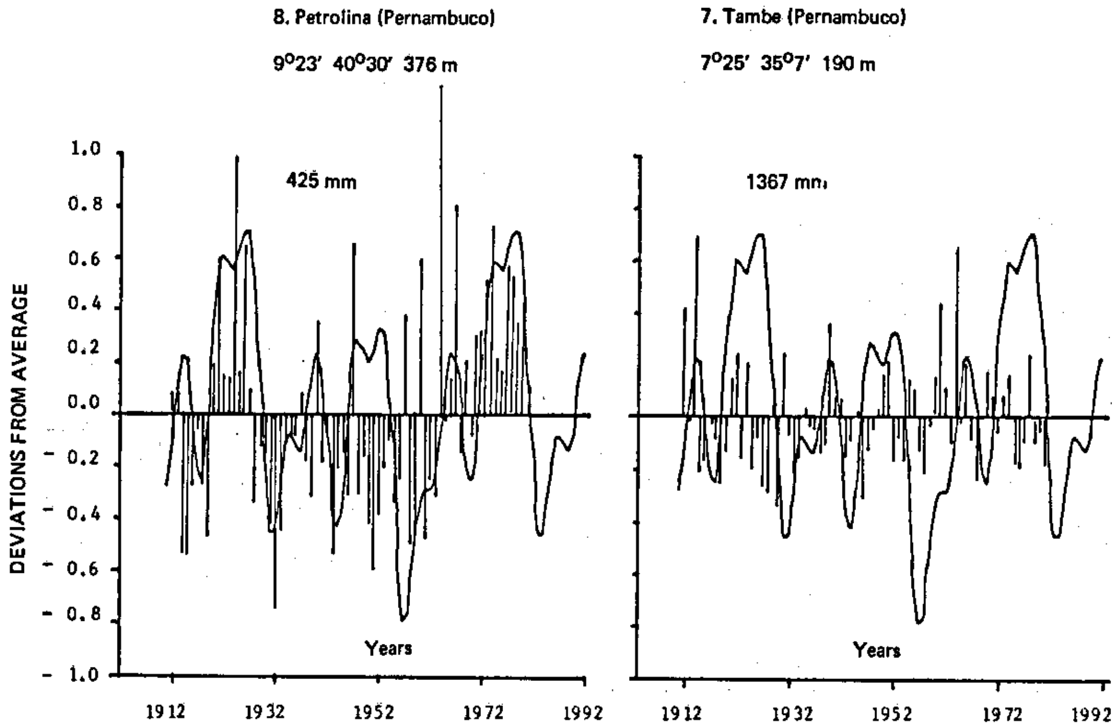

FIG. 10. Time series of Petrolina and Tambe precipitation.

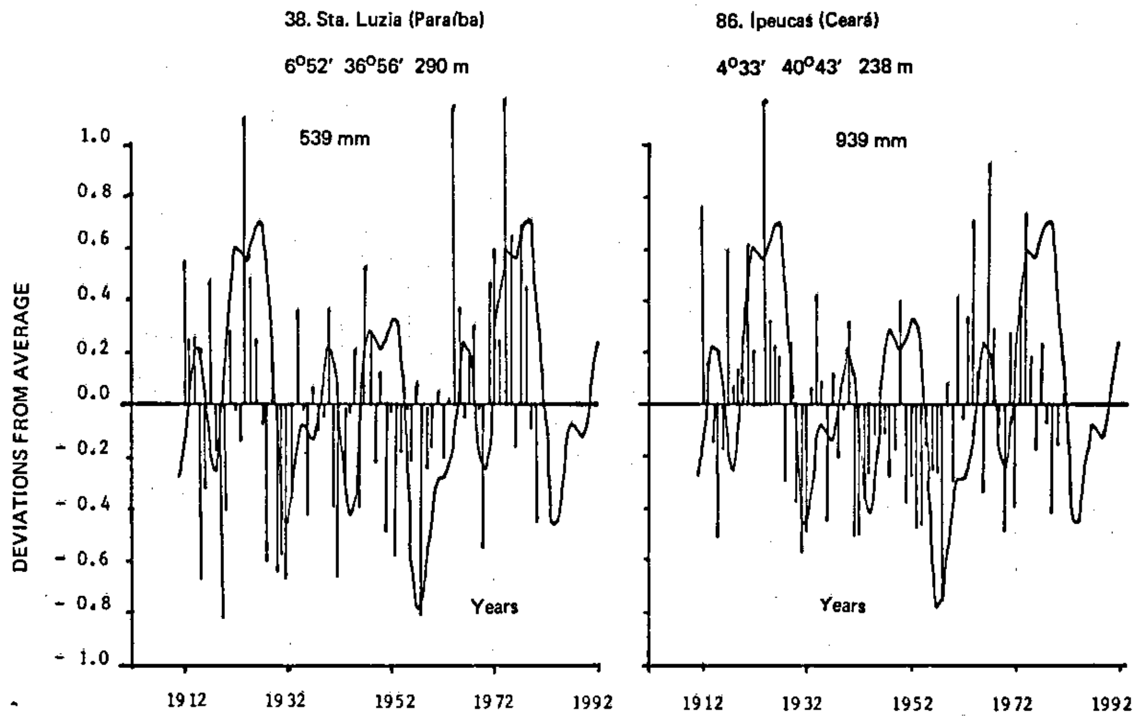

FIG. 11. Time Series of Sta. Luzia and Ipeucas precipitation.

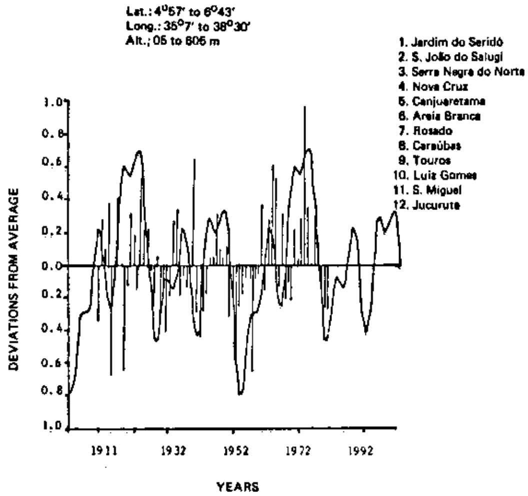

FIG. 12. Time series of the precipitation averages of 12 locations from Rio Grande do Norte.

DISCUSSION

Eventhough at many locations the data series present persistence, the spectral density pattern did not show much difference between locations with persistence and without persistence (Table 2). The difference in the spectral density patterns among the nearby locations is more associated with non-homogeneity in the data series. This character is also revealed in the coeffficient of variation (CV) of annual precipitation as irregular behavior (Fig. 2) in general CV decreases with increasing precipitation. These features are clearly evident in annual rainfall pattern presented in Fig. 14 and 15. Therefore, it is very important to isolate all those locations that do not fit into the general pattern of the surrounding locations and correct them using regression approach or grid method of extrapolation. The best way of identifying the non-homogeneous locations is through principal

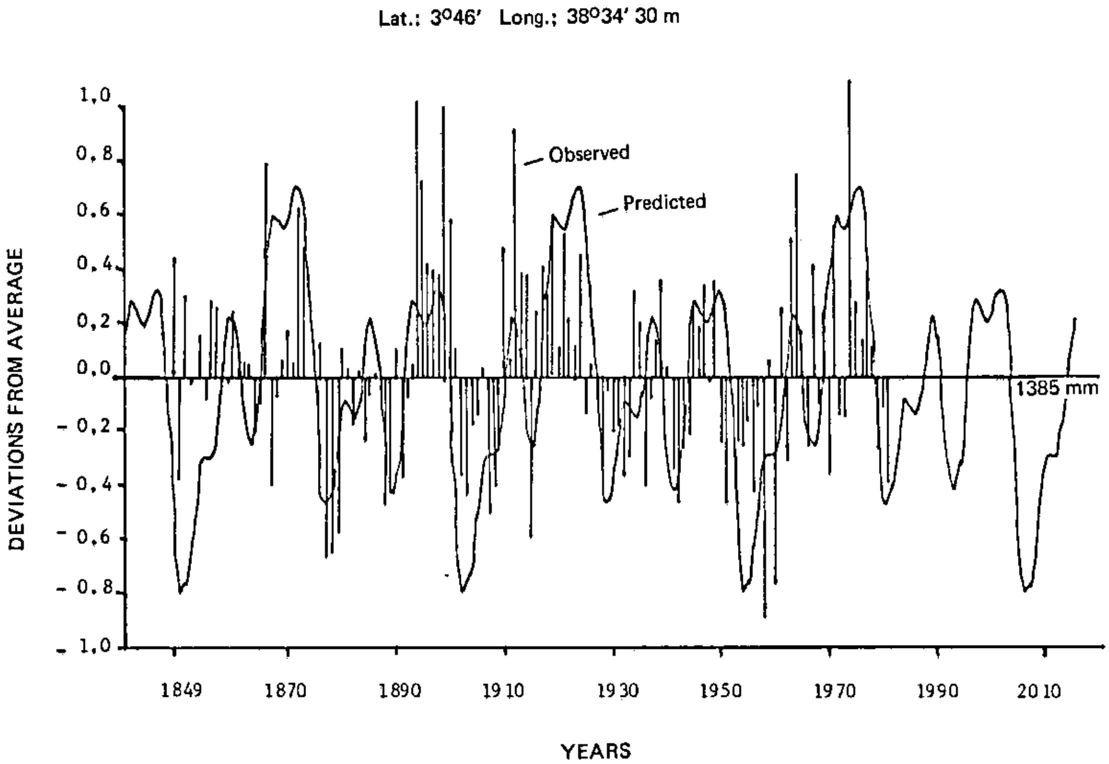

FIG. 13. Time series of Fortaleza (Ceará) precipitation.

TABLE 4. Amplitudes and phases of different cycles in Fortaleza data.

Cycle (Years)	Amplitude*	Phase** (degrees)
52	0.1875	6.923
26	0.3125	318.462
13	0.3125	110.769
6.5	0.1875	0.000

* Normalized amplitude presents the deviations from the average as a ratio of average.

** This phase angle corresponds to 1911 at Fortaleza.

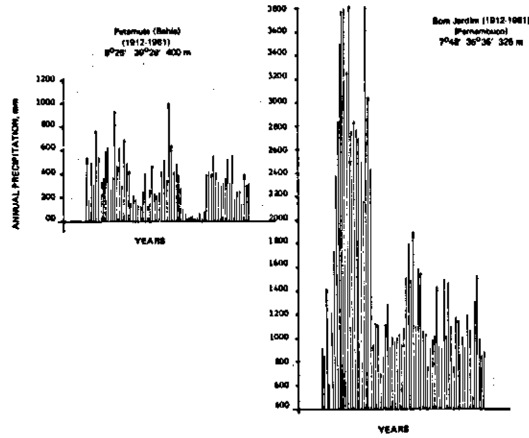

FIG. 14. Annual rainfall pattern at Patamute and Bom Jardim.

component analysis this is not attempted in this study.

In terms of significant cycles, the Northeast Brazil can be divided into three homogeneous zones, namely:

Region I - locations above 4°S lat.

Region II - locations in between 4-8°S lat.

Region III - locations below 8°S lat.

The boundaries of individual regions are variable between 4-5 and 8-10°S lat.

In all these regions, harmonics 0, 1 and 2 are significant at many locations. Harmonics 4-5 are significant at many locations above 8-10°S lat. (i.e. Regions I and II). Similarly, harmonics 9-12 and 13-15 are mainly confined to Regions I and II; while harmonic 9-12 is more prominent in

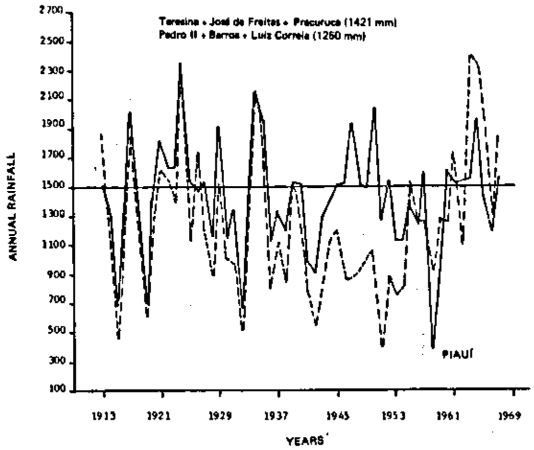

FIG. 15. Annual rainfall pattern for two growps of locations in Piauí.

Region I and harmonic 13-15 is more prominent in Region II. The harmonic 16-25 (QBO) is mainly significant in Region III. In Region III, the CV of annual precipitation is more uniform and presents slightly lower values compared to other regions. The CV is highly irregular in Region II and next in order comes Region I.

The auto-regression analysis of 133-year data series of Fortaleza (Region I) during 1849-1981 revealed four cycles, namely 52, 26, 13 e 6.5 years. The first three cycles are closer to harmonics 1, 2 and 4; while the fourth cycle (6.5 years) is slightly different from harmonic 9-12 (Fig. 3) the latter cycle is not significant in spectrum analysis of Fortaleza data series. Through iterative regression the normalized amplitudes and phase angles for these four cycles are found (Table 4). It is seen from Table 4 that the amplitudes of cycles 26 and 13 years are slighty higher than those of 52 and 6.5 years cycles. Strang (1979) reported a 13-year cycle in Fortaleza data. Girardi (1983) reported 26-year cycle. Carlos et al. (1982) found cycles 26 and 13 years as significant. However, they stated that these two cycles explained only 24% of variance in the data series. Reddy (1977) found cycle of 52-years in the data of onset of monsoon over a low latitude Kerala Coast (India). However, this cycle lags behind about 15-years to Fortaleza data. In the case of South Africa at a slightly higher latitude zone cycles of 60, 30, 20 and 10 are significant (Reddy & Singh 1981).

The integrated curve from these four cycles (Table 4) matches well with those locations in Region I and II. The matching is very poor in the case of Region III. Few locations present good agreement between observed and predicted curves prior to 1920's and later 1955's. There is a discrepency during 1920's to 1955's. Fig. 15 depicts the rainfall pattern of two groups of locations in Piauí. During 1920's to 1955's the two groups present opposite behaviour. Similar pattern is also evident in Rio Grande do Norte. However, the average pattern presents the solid line pattern (Fig. 12).

The observed cyclic variations in the climatic parameters were attributed to several forms of solar and lunar phenomena However, the present data series did not show any relation to either single or double sunspot cycles.

The major differences in the observed cycles in Region III when compared to Regions I and II may be due to the differences in the mechanisms that bring precipitation over these regions of the Northeast Brazil.

CONCLUSIONS

1. According to the cycles that are present in the annual precipitation data, the Northeast Brazil (excluding Maranhão and Piauí) could be divided into three homogeneous zones, namely: Region I comprises regions above 4-5°S lat.; Region III comprises of regions below 8-10°S lat.; and in between these two regions Region II.

2. It is evident from the auto-regression analysis that in Region I, the dry period (below average precipitation) commenced in 1979 may continue upto 1995 with a break for three years in 1988-1990. The wet period (above average precipitation) may commence in 1996 and terminate in 2003. Similar patterns are not evident clearly in Regions II and III, eventhough Region II resembles Region I.

3. The precipitation data of some locations present a non-homogeneity with time. This emphasises the importance of the checking and correcting the data series of different stations of the Northeast Brasil before they are actually used in any study.

4. The differences in the observed periodicities in the precipitation data may be due to either non--homogeneity in the data series or due to the differences in the mechanisms that bring precipitation to different parts of the Northeast Brazil or both.

REFERENCES

BLACKMAN, R.B. & TUKEY, J.W. The measurement of power spectra. New York, Dover publ. Inc., 1958.

CARLOS, A.N.; HORÁCIO, H.Y. & CORINA, C.F.Y. Previsão de secas no Nordeste pelo método das periodicidades: uso e abusos. s.l., INPE, 1982. (INPE 2344, RPE, 407).

GIRARDI, C. Previsão acertada: A seca do Nordeste já dura cinco anos e reabilita o prognóstico do Centro Técnico Aeroespacial. Veja, 26(1):60-1, 1983.

JENKINS, G.M. & WATTS, D.G. Spectral analysis and its applications. California, Holdan-Day Inc., 1968.

REDDY, S.J. Forecasting the onset of southwest monsoon over Kerala. Indian J. Meteorol. Hydrol. Geophys., 28:113-4, 1977.

REDDY, S.J. & AMORIM, M. da S. A method for the estimation of potential evapotranspiration and/or open pan evaporation over Brazil. Pesq. agropec. bras., Brasília, 19(3):247-67, mar. 1984.

REDDY, S.J. & AMORIM, M. da S. Dados climatológicos da precipitação, evapotranspiração potencial, radiação global solar e classificação da climática do Nordeste do Brasil. s.l., EMBRAPA-CPATSA, 1983.

REDDY, S.J.; AMORIM, M. da S. & ELPIDIO, M. da G. da S. A simple method for the estimation of global solar radiation over northeast Brazil. Pesq. agropec. bras., Brasília, 19(4):391-405, abr. 1984.

REDDY, S.J. & SINGH, S. Climate and soils of the semi--arid tropical regions of the would. s.n.t. Proceedings of Summer Institute on Production Physiology of dryland crops, held at APAU/ICAR, Rajendranagar, A.P., India, 1981.

STRANG, D. MAC, G.D. Utilização dos dados pulviométricos de Fortaleza, CE, visando determinar probabilidades de anos secos e chuvosos. São José dos Campos, SP, CIA/IAE, 1979. Relatório Técnico ECA - 03/79.

TUKEY, J.M. Sampling theory of power spectrum estimates. In: SYMP. ON APPL. AUTO-CORRE. ANALYSIS TO PHYSICAL PROBLEMS. Washinton, D.C., 1950. p.47-67. VS Nary Research, NAVE XOS - P - 735.

WORLD METEOROLOGICAL ORGANIZATION. Climatic Change. Geneva, Switzerland, 1966. WMO Technical Note, 79, WMO, 195 TP 100.