doi: 10.1590/S0102-261X1998000100004

QUASI-BIENNIAL AND QUASI-TRIENNIAL OSCILLATIONS IN THE RAINFALL OF NORTHEAST BRAZIL

R. P. Kane

The 12-monthly running means centered 3 months apart (4 values per year) of the rainfalls in NE (Northeast) Brazil were subjected to Maximum Entropy Spectral Analysis and results compared with similar analysis for several other parameters. Characteristics of northern NE and eastern NE rainfalls were almost similar but differed considerably from those of southern NE rainfall. In the QBO region, northern NE had small periodicities at 2.03, 2.45 years, eastern NE had strong periodicities at 2.26, 2.60 years while southern NE had no significant QBO. The 50mb equatorial zonal wind had a strongest peak at 2.33 years, a smaller peak at 2.64 years and a still smaller peak at ~2.00 years. The Southern Oscillation Index T-D (Tahiti minus Darwin atmospheric pressure) had peaks at 2.05, 2.57 years while EEP-SST (equatorial eastern Pacific sea surface temperature) had peaks at 2.10, 2.57 years. (North and South Atlantic SST) had peaks at (2.10-2.15) years while NE Brazil coast SST had 2.29 years and Wind Stress had 2.20 years. In the QTO region, 50mb wind had a small peak at 3.2 years and NE coastal Wind Stress at 3.3 years. All other parameters including all the 3 regional rainfalls of NE Brazil had significant peaks near 3.5 years. Peaks were also in the (4.5-5.0) year and (9.5-13.9) year bands. All the three rainfalls had moderate correlations with T-D and EEP-SST (~0.3) and with 50mb wind (~0.4). Rainfall correlations were higher with North and South Atlantic SST (~0.5) and with NE coastal SST (~0.6). The eastern NE rainfall had a high correlation (0.5) with NE coastal Wind Stress.

Key words: Quasi-biennial Oscillation; Northeast Brazil; Rainfall.

OSCILAÇÕES QUASI-BIENAIS E QUASI-TRIENAIS NAS PRECIPITAÇÕES DO NORDESTE DO BRASIL - *As médias móveis de 12 meses centradas a cada 3 meses (4 valores por ano) das precipitações no Nordeste do Brasil (NE) passaram por uma Análise Espectral de Máxima Entropia e os resultados foram comparados com análises similares para outros parâmetros. As características das chuvas no NE setentrional e oriental foram quase similares, mas diferiam consideravelmente das chuvas no NE meridional. Na região do QBO, o NE setentrional teve pequenas periodicidades em 2,03 e 2,45 anos, o NE teve fortes periodicidades em 2,26 e 2,60 anos enquanto o NE meridional não teve nenhum significante QBO. O vento zonal equatorial teve o pico mais forte em 2,33 anos, um pico menor em 2,64 anos e outro ainda menor em ~2,00 anos. O índice de oscilações meridional T-D (pressão atmosférica do Taiti, menos em Darwin), teve picos em 2,05 e 2,56 anos enquanto que a EEP-SST (temperatura da superfície do mar no Pacífico Oriental Equatorial) teve picos em 2,10 e 2,57 anos. O SST do Atlântico Norte e Sul teve picos em (2,10-2,15) anos enquanto o SST na costa NE do Brasil teve pico em 2,29 anos e a tensão dos ventos teve picos em 2,20 anos. Na região QTO, o vento em 50mb teve um pequeno pico em 3,2 anos e a tensão de ventos na costa NE teve pico em 3,3 anos. Todos os outros parâmetros, incluindo todos os 3 índices regionais de chuvas no NE do Brasil, tiveram picos significantes próximos de 3,5 anos. Apareceram também picos nas faixas de (4,5-5,0) anos e (9,5-13,9) anos. Todos os três índices de precipitação tiveram correlação moderada com T-D e EEP-SST (~0,3) e o vento em 50mb (~0,4). As correlações com o SST no Atlântico Norte e Sul foram mais altas (~0,5) e também com o SST costal do NE (~0,6). A precipitação do NE oriental teve alta correlação (0,5) com a tensão de vento costal do NE.*

Palavras-chave: *Oscilação Quasi-biennial; Nordeste do Brasil; Precipitação.*

Instituto Nacional de Pesquisas Espaciais - INPE
C. Postal 515, 12201-970
São José dos Campos, SP, Brasil.

INTRODUCTION

Several decades ago, a QBO (Quasi-biennial oscillation) was discovered in the low latitude stratospheric zonal winds (Reed et al., 1961; Veryard & Ebdon, 1961; Angell & Korshover, 1962). Details are given in Naujokat (1986). A theoretical explanation was given by Lindzen & Holton (1968) in terms of absorption in the stratosphere of vertically propagating Kelvin and Rossby-gravity waves generated in the troposphere. Plumb & Bell (1982) produced a numerical model, which reproduced many of the features of this QBO.

On the surface of the earth, QBO and QTO (Quasi-triennial oscillation) are shown by the phenomena ENSO, which consists of three main parameters. One parameter, El Ninos (EN), are warm water episodes occurring at the Peru-Ecuador coast (S. America). Quinn et al. (1978, 1987) has documented these events. The events last for several months and the warmth spreads to the equatorial eastern Pacific (EEP) giving the second parameter, warm EEP-SST (sea-surface temperature) events. Besides the EEP-SST, the El Ninos are also associated with another phenomenon viz. SO (Southern Oscillation) (third parameter), which is an atmospheric pressure see-saw due to an exchange of air between the South Pacific subtropical high and the Indonesian equatorial low. A simple SO index is the Tahiti (T, 18°S, 150°W) minus Darwin (D, 12°S, 131°E) pressure difference (T-D) which is normally a few mb but occasionally dips low to almost zero, or even negative. The minima of T-D occur during El Nino years.

Many meteorological parameters also show QBO and QTO (Landsberg et al., 1963; Landsberg & Kaylor, 1976; Kane & Gobbi, 1995; Kane, 1995, 1996). QBO of the 10mb wind seems to have some relation with Indian monsoon (Bhalme et al., 1987).

For rainfall in Brazil, particularly in the northeast, east and southern region, several factors are known to be relevant. Markham & McLain (1977) reported considerable influence of tropical Atlantic SST. Other factors, 700mb circulation pattern over the North Atlantic (Namias, 1977), meridional displacement and strength of the Intertropical Convergence Zone (ITCZ) (Hastenrath & Heller, 1977), Atlantic trade winds (Chung, 1982), rainfall systems associated with tropical disturbances moving westward from the Atlantic towards northeast Brazil (Ramos, 1975; Yamazaki & Rao, 1977; Rao et al., 1993), and southern hemisphere cold fronts or their remains moving northward

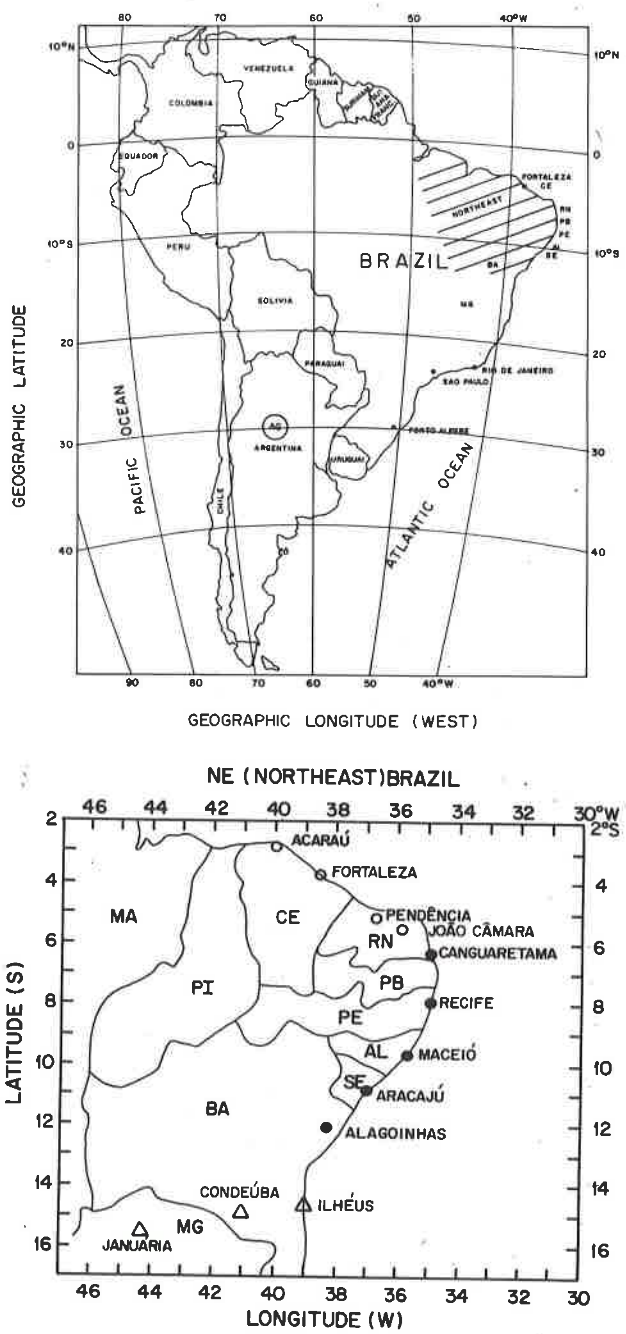

Figure 1 - (a) Map of the South-American continent, showing Brazil and its northeast (NE) (shaded) and the seaport Fortaleza (Ceará) and (b) Map of Northeast (Nordeste) Brazil. Open circles show locations of northern NE, full circles, eastern NE and triangles, southern NE.

Figura 1 *- (a) Mapa do continente Sul-Americano, mostrando o Brasil e sua região nordeste NE (sombreada) e o porto Fortaleza (Ceará); (b) Mapa do nordeste do Brasil. Os círculos abertos mostram localizações do norte do NE, os círculos cheios do leste do NE e os triângulos do sul do NE.*

along the northeast coast of Brazil (Kousky & Chu, 1978; Kousky, 1979). There is a well defined large-scale atmospheric circulation pattern related to the sea surface temperature anomalies in the tropical Atlantic (Hastenrath & Heller, 1977; Moura & Shukla, 1981). According to Hastenrath (1990), droughts in northeast Brazil can be due to an anomalously far northerly position of the intertropical convergence zone (ITCZ), reduced northeast trades and accelerated cross-equatorial flow from the southern hemisphere and anomalously warm surface waters in a zonal band across the tropical North Atlantic, contrasting with negative SST anomalies south of equator. The association with southern oscillation (SO) minima may come through the displacement of the near-equatorial trough northward. Hastenrath et al. (1984) and Hastenrath (1990) formulated prediction schemes involving zonal and meridional wind components over limited areas of the equatorial Atlantic, SST in tropical North and South Atlantic, SO index and pre-season rainfall itself in northeast Brazil, as predictors. A particularly interesting aspect is the relationship between the rainfall in northeast Brazil and the coastal wind in that region, through its effect on the positioning of the ITCZ. Servain & Seva (1987) indicated that the position of ITCZ was well-related to the minimum of the meridional component of the wind stress. Xavier & Xavier (1997) utilised this relationship for locating the position of the ITCZ in individual months and for predictions of rainfall.

Regarding periodicities, Markham (1974) reported a significant period near 13 years for rainfall at Fortaleza, Ceara. Kousky & Chu (1978) reported spectral peaks of 3-5 years for Northern NE, 2-3 years for Southern NE and 10-20 years for several stations in NE Brazil. Hastenrath & Kaczmarczyk (1981) showed that climatic variability was concentrated in different regions and, NE Brazil had a preference for 2.5, 5, 10 and 13-21 years. Chu (1984) examined data for Northern and Southern NE for 1911-1974 and found maximum power in the frequency bands 12.7-14.9, 4.5-4.9 and 2.2-2.4 years and examined the phase relationship between rainfall and surface circulation patterns. Kane & Trivedi (1988) made a Maximum Entropy Spectral Analysis of the annual rainfall series for the various parts of NE Brazil. Recently, Sperber & Hameed (1993) reported a phase locking of NE Brazil precipitation with SST (sea surface temperatures) in the Pacific and Atlantic sectors.

In the present paper, we use the 12-month running means of rainfall, centered 3 months apart, so that at least 8-12 data points per cycle would be used for estimating the QBO cycle. Also, we use MESA (Maximum Entropy Spectral Analysis) which detects peaks much more accurately than the broad bands reported by other workers, mentioned above.

DATA

Data for NE Brazil rainfall were available from FUNCEME (Fundação Cearense de Meteorologia e Recursos Hídricos) and CPTEC/INPE as monthly means. Data for 50mb (stratospheric) wind were obtained from Venne & Dartt (1990) who give a four-station average of monthly mean zonal wind at Gan (0.7°S, 73.2°E), Balboa (8.9°N, 79.6°W), Singapore (1.4°N, 103.9°E) and Canton (2.8°S, 171.7°W). Data for SO index (T-D) were obtained from Parker (1983) and were updated from Meteorological Data Reports. EEP-SST values were obtained from Angell (1981, and further private communication). Atlantic SST indices were obtained from Servain (1991) and SST and Wind stress data near NE Brazil coast were kindly supplied by Dr. Servain & Dr. Vianna privately.

METHODS OF ANALYSIS

Most of the parameters have strong seasonal variations. For study of larger periodicities, the seasonal variation was eliminated by calculating 12-monthly running means and values centered 3 months apart (4 values per year) were used for analysis.

For spectral analysis, we us MESA (Maximum Entropy Spectral Analysis, Burg, 1967; Ulrych & Bishop, 1975) which detects periodicities very accurately. The conventional BT (Blackman & Tukey, 1958) method gives power estimates at certain frequencies only, viz., k/2m where k=1, 2, ... , m and m is the lag, generally recommended as 25% of the data length. MESA gives estimates for *any* chosen frequency and the frequency steps can be chosen as close as one needs. For example, in a 100 data point sample, periods near 2.00 can be studied as closely as DT=0.01 and the accuracy is so good that 2.10 can be distinguished from 2.20 confidently. However, MESA has one defect. The power estimates are not very reliable (Kane & Trivedi, 1982). Hence, we use MESA only for detecting possible peaks T_k (k=1 to n) and these T_k are used in the expression:

$$f(t) = A_o + \sum_{k=1}^{n} \left[a_k \, Sin(2\pi t / T_k) + b_k \, Cos(2\pi t / T_k) \right] + E$$

$$= A_o + \sum_{k=1}^{n} r_k \, Sin(2\pi t / T_k + \phi_k) + E \qquad (1)$$

where f(t) is the observed series and E the error Factor. The parameters A_o, (a_k, b_k) and their standard errors are obtained by a Multiple regression analysis (MRA, Bevington, 1969). From these, the amplitudes r_k and their standard error σ_r (same for all r_k in this methodology) can be estimated. In MESA, there is a variable called LPEF (length of the prediction error filter). At low LPEF, only small periodicities are revealed. For higher LPEF, larger periodicities are revealed (even those approaching the total data length) but lower periodicities show peak-splitting. Our experience shows that an LPEF of 50% of the data length reveals quite satisfactorily all periodicities up to about half the data length (e.g. T up to 50 in a 100 data point sample). Higher periodicities do appear but the error may be 10% or more (e.g. T=80±8).

Besides spectral analysis, we carry out a cross-correlation analysis, which shows, firstly, whether two parameters are well-related (correlations above, say, 0.5) and secondly, with what phase shift, if any.

RESULTS OF VISUAL INSPECTION

Fig. 2 shows a sample plot for the rainfall at Fortaleza, Ceara (4°S, 39°W), for 1951-1969. The top plot (1a) shows 3 monthly rainfall totals (DJF, MAM, JJA, SON). The peak rainfall is in MAM but varies considerably from year to year (300 to 1300 mm). The seasonal variation is eliminated (or considerably minimized) in the 12-monthly running averages shown in Fig. 2(b) as thin lines (4 points per year). An oscillatory structure is visible though not uniformly all through. To isolate it from long-term variations, 3-year running means were calculated and are shown as the smooth, thick line in Fig. 2(b) while the difference between the thin and thick line is shown in Fig. 2(c). We will, hereafter, call this FR (12-36). The QBO, QTO are now clearly visible, though the peak spacing is irregular. To check whether subtracting the 3-year means caused any distortion of the QBO, QTO, we calculated 4-year (16 season) and 5-year (20 season) running means and subtracted these from the 12-monthly running means. The residues are shown in Fig. 2(d) as FR (12-48) and in Fig. 2(e) as FR (12-60). Fig. 2(c, d, e) are very similar to each other. Hence, we will use FR (12-36) as a good representative of the QBO, QTO, corrected for long-term trends.

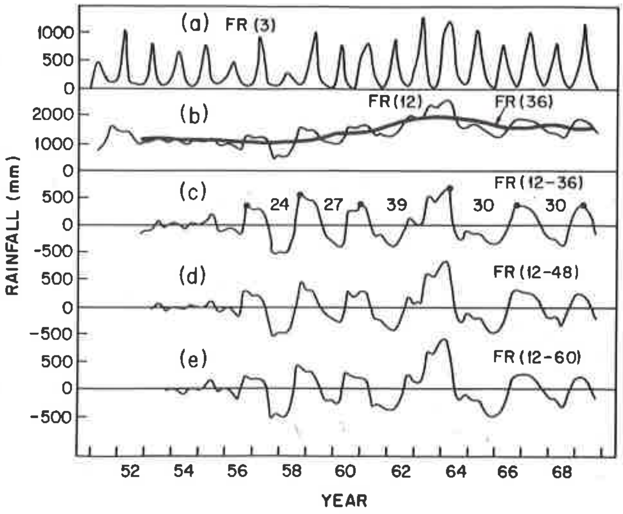

Figure 2 - (a) Fortaleza rainfall, 3-monthly values (DJF, MAM, JJA, SON) for 1951-1969); (b) 12-monthly (4 season) running means FR (12) (thin line) and 3-year (12 season running means FR (36) (smooth, thick line); (c) the difference FR (12-36) of 12-monthly and 3-year running means; (d) the difference FR (12-48) of 12-monthly and 4-year running means and (e) the difference FR (12-60) of 12-monthly and 5-year running means.

Figura 2 *- (a) Precipitação pluviométrica em Fortaleza, para dados de três meses (DJF, MAM, JJA, SON) para o período de 1951-1969; (b) Médias móveis para 12 meses (4 estações) FR(12) (linha fina) e média móvel para 3 anos FR (36) (suavização, linha espessa); (c) Diferença entre as médias móveis de 12 meses e 3 anos, FR (12-36); (d) Diferença entre as médias móveis de 12 meses e 4 anos, FR (12-48); (e) Diferença entre as médias móveis de 12 meses e 5 anos, FR (12-60).*

POWER SPECTRUM ANALYSIS

Fig. 3(a) shows the MESA spectra for 1951-1990, for the 12-monthly means FR (12) and the residuals FR (12-36). In FR (12), T=2.06, 3.50, 5.2, 11.5 and 28 years are prominent peaks. In FR (12-36), T=2.07 and 3.50 years (QBO and QTO) amplitudes remain intact, while T=5.2, 11.5 and 28 year amplitudes have reduced considerably, as expected. Thus, for studying QBO and QTO only, FR (12-36) would be quite adequate. In Fig. 3(a), the ordinate is log (Power) and in FR (12), T=11.5 years seems to have overwhelming power, followed by T=3.50 and T=2.06 years, while T=5.2 and 28 years have lesser power. However, our experience has been that in MESA, these relative proportions are not reliable (Kane & Trivedi, 1982). Hence, a Multiple Regression Analysis (Eq. 1) was carried out using all these periodicities (as also some of the smaller ones) as T_k. The amplitudes are shown in Fig. 3(b). For FR (12), T=11.5 year is still the largest peak and T=28 years, the second largest, while T=3.5 and 5.2 years are almost equal and T=2.07 only slightly lesser. These results are for 40 years data (1951-1990) and, with 5-10% error, are similar to the periodicities T=2.07, 3.6, 12.9, 25.1 years reported by Kane & Trivedi (1988) for the longer (1849-1976, 128 years) series of Fortaleza. For FR (12-36), T=2.07 and 3.5 years are the most prominent and of comparable amplitudes, followed by additional QBO peaks at T=2.31 and 2.49 years, while T=4.4 and 5.2 years are comparable to each other but of reduced size. Thus, FR (12-36) is not useful for studying periods exceeding 4.0 years. The hatched portion indicates the 2s limit (95% confidence level, a priori) and the periodicities mentioned above are significant far above the 2s limit.

However, it may be noted that the 12-monthly running means are obtained by calculating running means over four consecutive seasonal (3-monthly) values. Hence, even though there are 4 points per year, there is only one

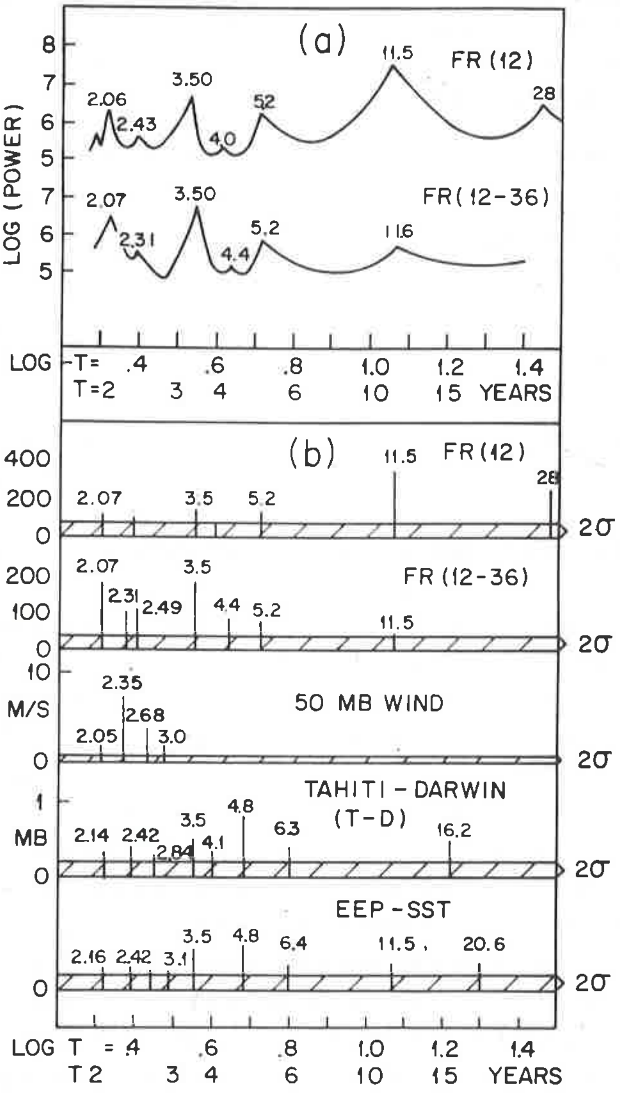

Figure 3 - (a) MESA (Maximum Entropy Spectral Analysis) of the 12-monthly means FR (12) and the difference FR (12-36) of 12 monthly and 3-year means of Fortaleza rainfall series (1951-1990). Numbers indicate periodicity peaks in years and (b) amplitudes of the various periodicities observed in FR (12) and FR (12-36) of Fortaleza rainfall and in 50mb zonal wind, Southern Oscillation Index Tahiti minus Darwin (T-D) atmospheric pressure and EEP-SST (equatorial eastern Pacific sea surface temperature). The hatched portions indicate 2s limits.

***Figura 3** - (a) MESA (Maximum Entropy Spectral Analysis - Análise da Máxima Entropia Espectral) para as médias de 12 meses FR (12) e para as diferenças FR (12-36) da precipitação pluviométrica de Fortaleza no período de 1951-1990; (b) Amplitudes das várias periodicidades observadas em FR (12) e em FR (12-36) da precipitação pluviométrica de Fortaleza e em 50mb de vento zonal, Índice de Oscilação Meridional Tahiti menos Darwin (T-D) da pressão atmosférica e EEP-SST (Equatorial Eastern Pacific Sea Surface Temperature - Temperature da Superfície do Oceano Pacífico Equatorial Oriental). A porção hachurada indica os limites 2s.*

independent point per year. Hence, the 2s limits (hatched portions) shown in Fig. 3 (and in later similar figures) are in reality, equivalent to s levels only. Hence, peaks will be significant at a 95% confidence level only if these protrude above 2 times the hatched area. In FR (12-36) in Fig. 3(b), many of the QBO, QTO peaks do exceed the 4s level.

The other plots in Fig. 3(b) are for 50mb wind, SO index (T-D) and EEP (equatorial eastern Pacific) SST. Similarities or dissimilarities between periodicities do not necessarily imply physical relationships or lack of these. But a comparison of these spectra indicates the following:

1)The 50mb wind shows only QBO peaks, and no other periodicities (QTO etc.). The SO index (T-D) and EEP-SST have spectra very similar to each other and different from the 50mb wind spectra, with more emphasis in the QTO (3.5 years) and 4-6 year region. Since Fortaleza rainfall also has a similar pattern, it is tempting to conclude that rainfall is more related to the ENSO phenomenon than to the stratospheric wind.

2)All these parameters have QBO. MESA is very accurate in this region and the several peaks in the QBO region are probably all meaningful. Three specific bands seem to be involved viz. 2.00-2.15, 2.30-2.50 and 2.65-2.85 years. In 50mb wind, T=2.35 is most prominent. In rainfall 2.07 years is most prominent; but 2.31 and 2.49 are also significant. In (T-D) and SST, all these QBO exist, but not very significant. Thus, one may argue that the rainfall QBO is contributed at least to some extent by the 50mb wind QBO. There seems to be a possibility that part of stratospheric wind QBO and the ENSO phenomena may be interrelated. Rasmusson et al. (1990) asserts that the ENSO has a *biennial* mode, dissimilar to the stratospheric wind QBO. But Gray et al. (1992) hypothesize a mechanism by which stratospheric QBO influences ENSO variability while Geller & Zhang (1991) and Geller et al. (1997) illustrate a mechanism by which SST variations modulate tropical wave activity and force a stratospheric zonal flow with the same period as SST-QBO.

3)T=3.5 years in rainfall is exactly similar to those of (T-D) and SST. T=5.2 years in rainfall may or may not be related to the T=4.8 and 6.4 years of (T-D) and SST. T=11.5 years of rainfall is seen is SST but not in (T-D).

Table 1 lists the periodicities significant above a 4s (in reality, 2s) level, for 1951-1990 data.

	Periodicity ranges (years)				
Parameter (1951-1990)	2.00-2.30	2.31-2.60	2.6-3.0	3.0-4.0	4.0-7.0
FR (12-36)	2.07	2.31, 2.49		3.5	4.4, 5.2
50 mb wind	2.05	2.35	2.68, 3.0		
(T-D)		2.42		3.5	4.8, 6.3
SST				3.5	4.8, 6.4

Table 1 - Periodicities significant at a 95% confidence level, for 1951-1990, for Fortaleza rainfall, 50mb wind, (T-D) and Pacific SST.

Tabela 1 - *Periodicidades significativas ao nível de confiança de 95%, para 1951-1990, para a precipitação pluviométrica de Fortaleza, ventos de 50mb, (T-D) e SST no Pacífico.*

Earlier workers mentioned broad bands near 2.2-2.4, 4.5-4.9 and 12.7-14.9 years (Chu, 1984). Our finer analysis reveals very narrow periods (e.g. 3.5 years) prevailing in many of these parameters. It is tempting to consider 3.5 and 5.2 years as third and second harmonics of sunspot cycle (10-11 years), but this may be a chance coincidence.

CROSS-CORRELATION ANALYSIS

Fig. 4 shows the cross-correlation results. The top plot shows a maximum correlation of ~0.4 and a phase shift of ~2-3 seasons i.e. Fortaleza rainfall maxima occurring 2-3 seasons before the 50mb westerly wind maxima. The small correlation, though highly significant (0.40±0.07), is not very encouraging. But, in the next two plots also, the Fortaleza rainfall shows low correlations with equatorial eastern Pacific SST or SO index (T-D). Low correlations (~0.4) between NE Brazil rainfall and SO index or Pacific SST have been reported earlier (Ropelewski & Halpert, 1987; Rogers, 1988; Aceituno, 1988) but have been interpreted as indications of meaningful relationships between these parameters. By the same token, a relationship between Fortaleza rainfall and 50mb wind may be considered as meaningful. The exact mechanism needs further investigation. For the Indian summer monsoon, amongst several parameters, the 50mb ridge-trough east-west extent over northern hemisphere during winter (Thapliyal, 1984) and westerly wind at 10mb (Bhalme et al., 1987) seem to be important. For NE Brazil rainfall, the empirically based prediction methods of Hastenrath (1990) have not yet included stratospheric winds as a parameter.

The fourth plot in Fig. 4 shows correlation between (T-D) and Pacific SST. As expected, the correlation is very

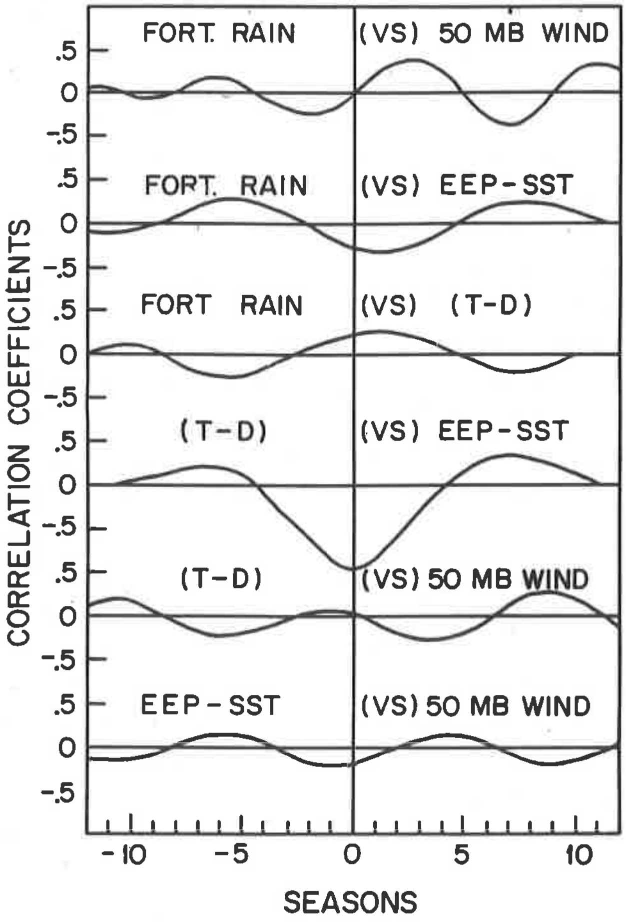

Figure 4 - Cross-correlations between Fortaleza rainfall parameter FR (12-36) and 50mb wind, EEP-SST and (T-D) and, between each other.

Figura 4 *- Correlação cruzada entre os parâmetros da precipitação pluviométrica de Fortaleza FR (12-36) e 50mb de vento zonal, EEP-SST e (T-D), e entre cada outro.*

high and negative (-0.8) as expected, as (T-D) minima are very well associated with SST maxima. The other two plots show low but significant correlations (0.30±0.08) between ENSO and 50mb wind, due to the QBO part being similar. Whether this implies an impact of ENSO on the stratospheric winds (or vice versa) is a mute question.

ATLANTIC PARAMETERS

In the Atlantic region, the temperature variations are dissimilar in the northern and southern hemisphere. Fig. 5 shows a plot of various parameters. The top plot (a) shows

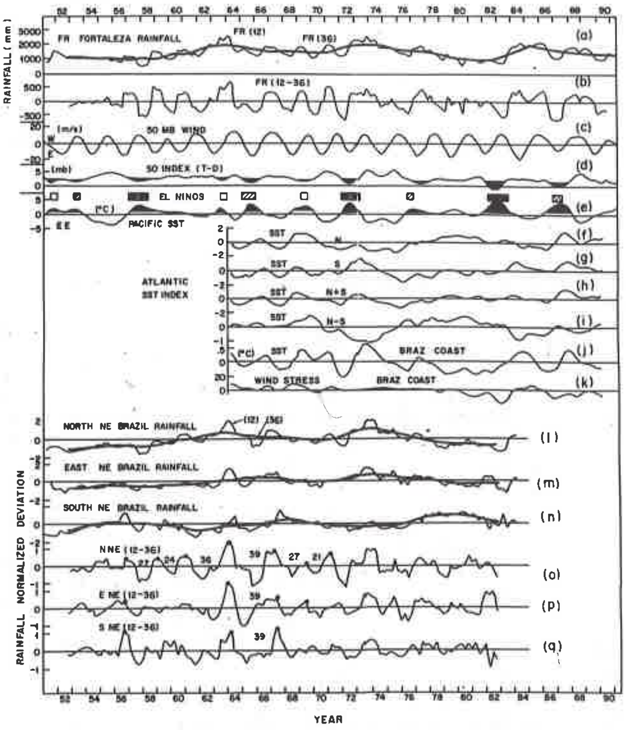

Figure 5 - Plots for 1951-1990 of: (a) Fortaleza rainfall 12-monthly running means FR (12) (thin lines) and superposed 3-year running means FR (36) (smooth, thick line); (b) difference FR (12-36); (c) 50mb equatorial zonal wind; (d) Southern Oscillation Index (T-D) (Tahiti minus Darwin atmospheric pressure); (e) equatorial eastern Pacific SST (sea surface temperature); (f) North (N) Atlantic SST; (g) South (S) Atlantic SST; (h) (N+S)/2; (i) (N-S)/2; (j) NE Brazil coast SST; (k) NE Brazil coast wind stress and for (l, m, n, o, p, q) Rainfall in northern, eastern and southern NE, 12-monthly (thin line), 3-year (smooth, thick superposed line) and (12-36) values.

Figura 5 *- Curvas para o período de 1951-1990 de: Médias móveis de 12 meses da precipitação pluviométrica de Fortaleza (linha fina) superpostas as de 3 anos FR (36) (linha espessa). (a) Diferença FR (12-36); (b) Vento zonal equatorial 50mb; (c) Índice de Oscilação Meridional (T-D) (pressão atmosférica Tahiti menos Darwin); (d) Pacífico oriental equatorial SST (temperatura da superfície do mar); (e) Atlântico norte SST; (f) Atlântico Sul SST; (g) (N+S)/2; (h) (N-S)/2; (i) Costa do nordeste do Brasil SST; (j) Intensidade do vento na costa do nordeste do Brasil; (l, m, n, o, p, q) Precipitação pluviométrica no norte, leste e sul do nordeste, linha fina (12 meses), linha espessa (3 anos) e (12-36).*

the 12-monthly running means (thin lines) of Fortaleza rainfall FR (12) and the 3-year running means (thick line) FR (36). The next plot (b) shows their difference FR (12-36). The third plot (c) shows the 12-monthly running means of 50mb wind. The plots (d) and (e) are 12-monthly running means of SO index (T-D) and EEP-SST while the in-between rectangles show El Ninos (full = strong; hatched = moderate; blank = weak). (T-D) minima and SST maxima are painted black and, in general, coincide with each other and with moderate or strong El Ninos. 1976-77 is a glaring exception when El Nino and SST maximum occurred in 1976 while (T-D) minimum occurred in 1977. Deser & Wallace (1987) have pointed out such dephasings.

The plots (f) and (g) show 12-monthly running means of the SST indices for northern N (28°N-5°N) and southern S (5°N-20°S) Atlantic as given in Servain (1991). Plot (h) is their average (N+S)/2 while plot (i) is their average difference (N-S)/2. Moura & Shukla (1981) mention that a simultaneous occurrence of warm waters in the tropical North Atlantic and cold waters in the equatorial South Atlantic, induce a meridional circulation cell, with subsidence over NE Brazil. However, plots (f) and (g) do not seem to show opposite variations (Atlantic dipole) all the time. The plot (j) shows SST variations near the NE Brazil coast (see Fig. 1) and plot (k) shows the zonal pseudo-wind stress (product of the intensity of the eastward wind velocity and the total wind speed) in the same region.

Since the Atlantic data are for a shorter period (1964-1990, 27 years) and the spectral characteristics may change slightly from period to period, MESA was performed for 1964-90 also for all the parameters. Fig. 6 shows the amplitudes for 12-monthly mean series. For Fortaleza rainfall, 50mb wind, (T-D) and EEP-SST, the peaks in Fig. 6 for 1964-90 differ slightly from those of Fig. 3 for 1951-90, indicating that the peaks may not be fully stationary. In the Atlantic, (N-S) shows the largest peak at 12.3 years, temptingly similar to 12.5 years in Fortaleza rainfall. Thus,

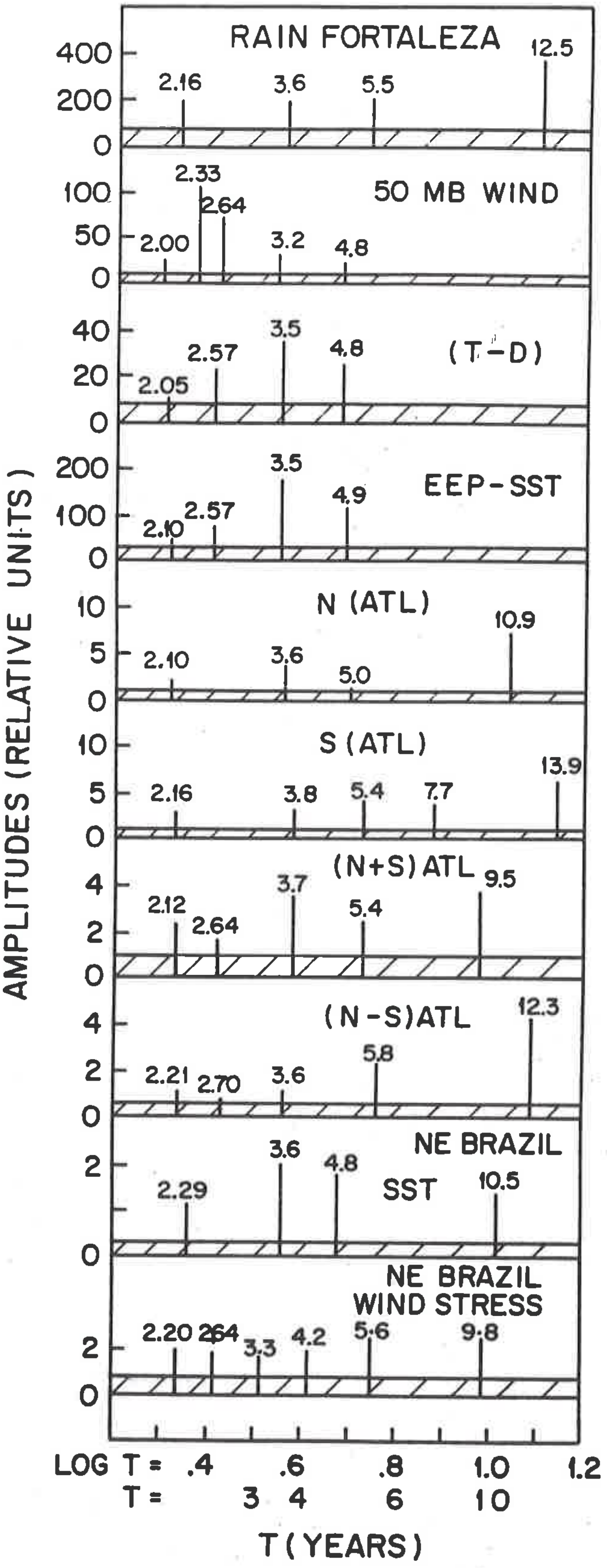

Figure 6 - Spectra for 1951-1990 for the 12-monthly running means of various parameters. The hatched portions indicate 2s (a priori) limits.

***Figura 6** - Espectro para o período de 1951-1990, para as médias móveis anuais dos vários parâmetros. As porções hachuradas indicam os limites 2s.*

the long-term peaks in the Fortaleza rainfall are probably due to Dipole effect in the low latitude Atlantic SST.

The most prominent peak at 2.33 years in the 50mb wind for 1964-1990 (not very different from the 2.35 year peak in 1951-1990), is not seen in any SST, Atlantic or Pacific parameter, nor in the Fortaleza rainfall. Thus, this peak is stratospheric only. On the other hand, the smaller peak at 2.64 years and the still smaller one near 2.00 years in stratospheric wind QBO are seen in (T-D) and EEP-SST (2.05-2.10; 2.57) and may be indicative of links between stratospheric wind and ENSO. Gray et al. (1992) have described hypothetical mechanisms by which QBO of lower stratospheric zonal winds alters the distribution of intense deep convective activity throughout the tropical west Pacific, while Geller & Zhang (1991) and Geller et al. (1997) explore a mechanism by which SST variations modulate tropical wave activity which may force stratospheric zonal flow with the same period as the QBO of SST.

The plots in the bottom part of Fig. 6 show spectra for sea-surface temperatures near the NE Brazil coast. Here, 3.6 and 4.8 years are the prominent peaks, similar to N and S Atlantic SST. A smaller peak at 2.29 years resembles more the 50mb wind peak 2.33 years than the Atlantic SST peaks in this band. For wind stress near NE Brazil coast, the QBO peaks (2.20, 2.64 years) match the (N+S) Atlantic SST peaks (2.12, 2.64 years) but 3.3, 4.2, 5.6, 9.8 match only roughly with (N+S) SST peaks 3.7, 5.4, 9.5 years.

Table 2 shows the periodicities significant above a 4s (in reality, 2s) level, for the shorter period 1964-1990.

Parameter (1964-1990)	Periodicity ranges (years)					
	2.00-2.30	2.31-2.60	2.6-3.0	3.0-4.0	4.0-8.0	7.0-14.0
FR (12)	2.16			3.6	5.5	12.5
50 mb wind	2.00	2.33	2.64	3.2	4.8	
(T-D)		2.57		3.5	4.8	
SST		2.57		3.5	4.9	
N (ATL)	2.10			3.6		10.9
S (ATL)	2.16			3.8	5.4, 7.7	13.9
(N+S)ATL	2.12	2.64		3.7	5.4	9.5
(N-S)ATL	2.21			3.6	5.8	12.3
SST (NE BR)	2.29			3.6	4.8	10.5
WIND(NE BR)	2.20	2.64		3.3	4.2, 5.6	9.8

Table 2 - Periodicities significant at a 95% confidence level, for 1964-1990, for Fortaleza rainfall, 50mb wind, (T-D), Pacific SST and Atlantic parameters.

Tabela 2 *- Periodicidades significativas ao nível de confiança de 95%, para 1964-1990, para a precipitação pluviométrica de Fortaleza, ventos de 50mb, (T-D) e parâmetros de SST no Pacífico e no Atlântico.*

Fig. 7(a,b) show the cross-correlations. Fortaleza rainfall (FR 12) (Fig. 7a) has a low correlation (0.30) with North Atlantic SST and a higher (0.45) correlation with South Atlantic SST and moderate (0.40) correlations with (N+S) and (N-S). The correlation with (N-S) is probably due to the common 12.5 years periodicity. The rainfall correlations are higher with SST of NE Brazil coast (0.5), and also with NE Brazil coast wind stress (0.4). Thus, the local environment seems to be of greatest importance. However, these cannot be useful for prediction purposes, because the phases *coincide*. On the other hand, the rainfall maxima (zero line) occur a few seasons *after* the North and South Atlantic (N or S or N+S) SST maxima. Thus, the December-January Atlantic SST warming could be an indicator of excess rainfalls. The (N-S) *coincides* with rainfall maximum and has no prediction potential.

How is the eastern equatorial Pacific (EEP) SST related to the Atlantic SST? Fig. 7(b) shows the cross-correlations. There is good correlation with North Atlantic SST (0.65±0.05) but lesser with South Atlantic SST (0.45±0.06), good correlation with (N+S) (~0.6) and much lesser with (N-S) (~0.25). Correlation between EEP-SST and NE Brazil coast SST is also high but with a phase shift of ~3-4 seasons. Thus, whereas some relationship is indicated, the Atlantic and Pacific parameters are not fully related. Only about 40% variance is common.

The maximum correlations (at ~2 season phase shift) between Fortaleza rainfall and S. Atlantic SST, N. Atlantic SST, 12 monthly running means of (T-D), Pacific SST and 50mb wind were 0.52, 0.32, 0.25, 0.18 and 0.11 (decreasing order). We shifted Fortaleza rainfall values 2 seasons earlier and conducted a multivariate analysis. The single variable correlation between rainfall and South Atlantic SST (0.52) increased to a multiple correlation of 0.69 when North Atlantic SST was also considered, but remained ~0.69 when (T-D), Pacific SST and 50mb wind were added to the list of variables one by one. Thus, the Atlantic sector SST seems to play a major role while Pacific SST, SO index and 50mb wind do not seem to be of much consequence. On the other hand, the NE coastal parameters viz. SST and Wind stress are each highly correlated to Fortaleza rainfall (0.66 and 0.57) and when considered together in a bivariate analysis, gave a multiple correlation of 0.76 which increased to 0.80 when one more variable S. Atlantic SST was added but increased only slightly (0.81) by adding the other parameters. The northeast Brazil coastal parameters (SST

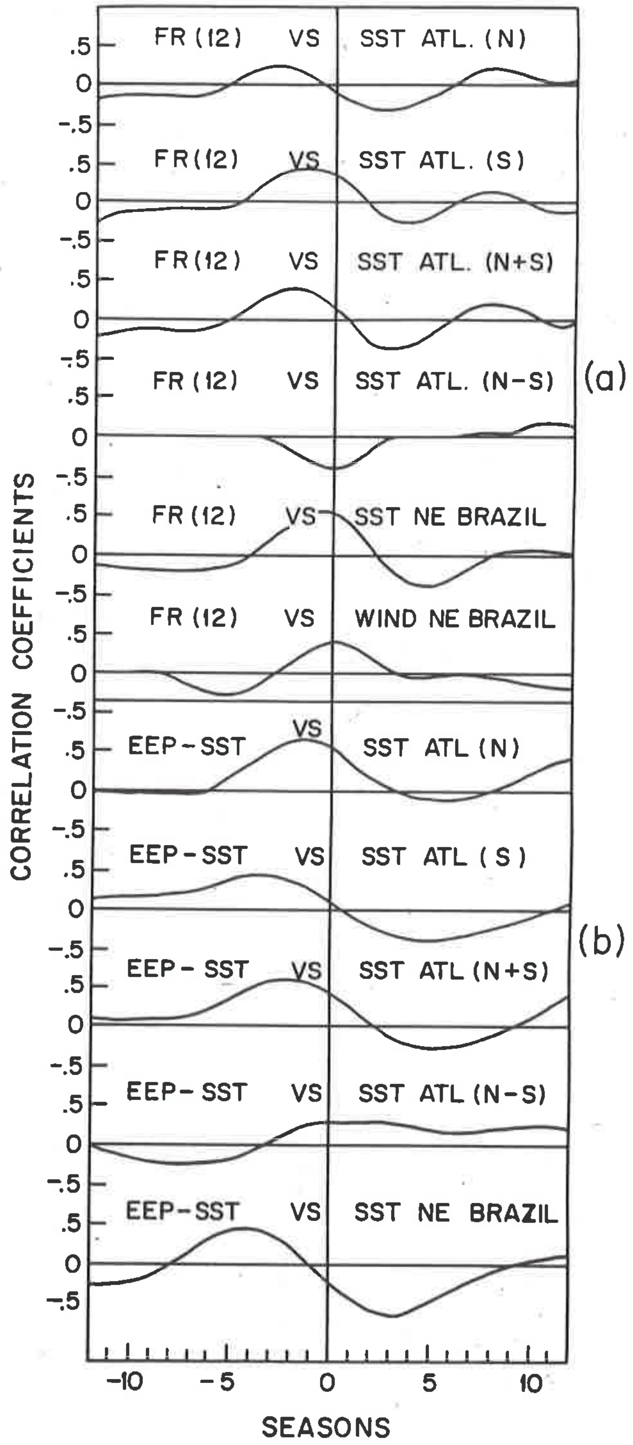

Figure 7 - Cross-correlations between: (a) Fortaleza rainfall 12-monthly running means FR (12) and the Atlantic SST parameters N, S, N+S, N-S and the NE Brazilian coastal SST and Wind Stress and (b) equatorial eastern Pacific sea surface temperature EEP-SST and the Atlantic SST and NE Brazilian coastal SST.

and wind stress) probably affect the Fortaleza rainfall through changes in the ITCZ locations (Servain & Seva, 1987; Xavier & Xavier, 1997)

NONUNIFORMITY OF NE BRAZIL RAINFALL

Though NE Brazil is drought-prone, the characteristics of rainfall in all parts of NE are not similar (Kousky & Chu, 1978; Kousky, 1979; Chu, 1983, 1984; Rao et al., 1993). To check the spatial variability, we selected several locations mostly on or near the NE Brazil coast as shown in Fig. 1(b).

Fig. 8(a) shows the monthly average rainfalls for 1951-1985, confirming that whereas locations in northern NE have maximum rainfall in March-April, the maximum shifts to the middle of the year for eastern NE even up to 12°S, and at southern latitudes, to later months. Fig. 8(b) shows the spectra for these locations. As can be seen, the spectra are varied. The QBO is prominent in northern NE and very prominent in some eastern NE locations. T ~3.5 years seems to be significant in almost all locations. T ~4.3 years appears in some locations while T=(4.6-7.1) years and (9.0-11.7) years appear in others. Chu (1984) mentions a phase lag of ~1.3 years between northern and southern NE rainfalls for the 12.7-14.9 year band, approximately out of phase for the 4.5-4.9 year band and approximate coincidence for the 2.2-2.4 year band. In Fig. 8(b), the only periodicity seen in all locations is near 3.5 years; but even this varies in the range (3.3-3.6) years. Part of this variation could be due to idiosyncrasies of individual locations. Hence, we combined the data into 3 major groups viz. Acaraú, Fortaleza, Pendência, João Câmara representing northern NE; Canguaretama, Recife, Maceió, Aracajú, Alagoinhas representing eastern NE; and, Ilhéus, Condeúba, Januária representing southern NE. The lower part of Fig. 5 shows the plots of the 12 monthly running means (thin lines), the 3-year (36 season) running means (superposed smooth,

Figura 7 - *Correlações cruzadas entre: (a) Médias móveis anuais FR (12) da precipitação pluviométrica de Fortaleza e os parâmetros Atlânticos SST: N, S, N+S, N-S e SST e a tensão do vento do litoral do NE brasileiro; (b) EEP-SST (Temperatura da Superfície do oceano Pacífico Leste Equatorial) e SST Atlântico e SST do litoral do NE brasileiro.*

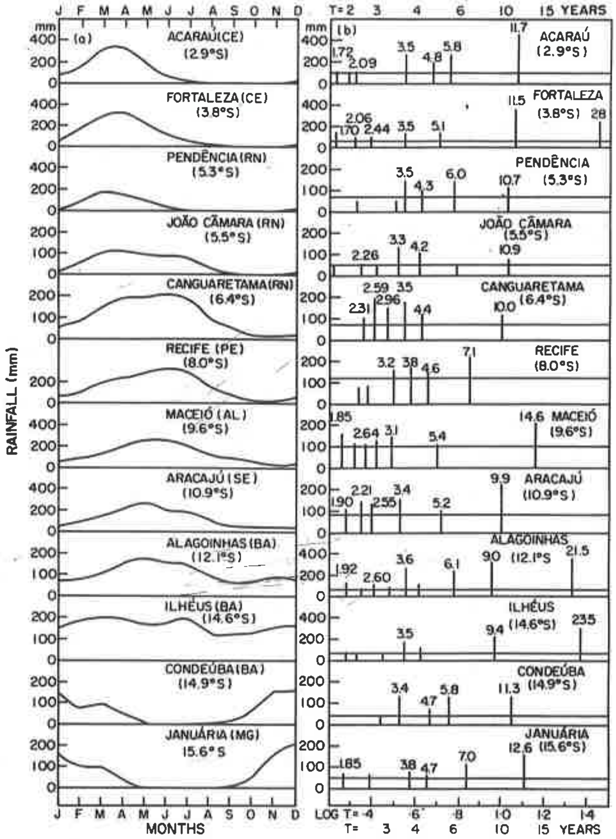

Figure 8 - (a) Average monthly rainfalls for 1951-1985 at various locations at or near the NE Brazil seacoast and (b) Spectra of rainfall series (1951-1985). The hatched portions indicate 2s (a priori) limits.

Figura 8 *- (a) Médias mensais da precipitação pluviométrica para o período de 1951-1985 em vários locais do litoral do nordeste brasileiro; (b) Espectro das séries de precipitação pluviométrica para o periodo de 1951-1985. As porções hachuradas indicam os limites 2s.*

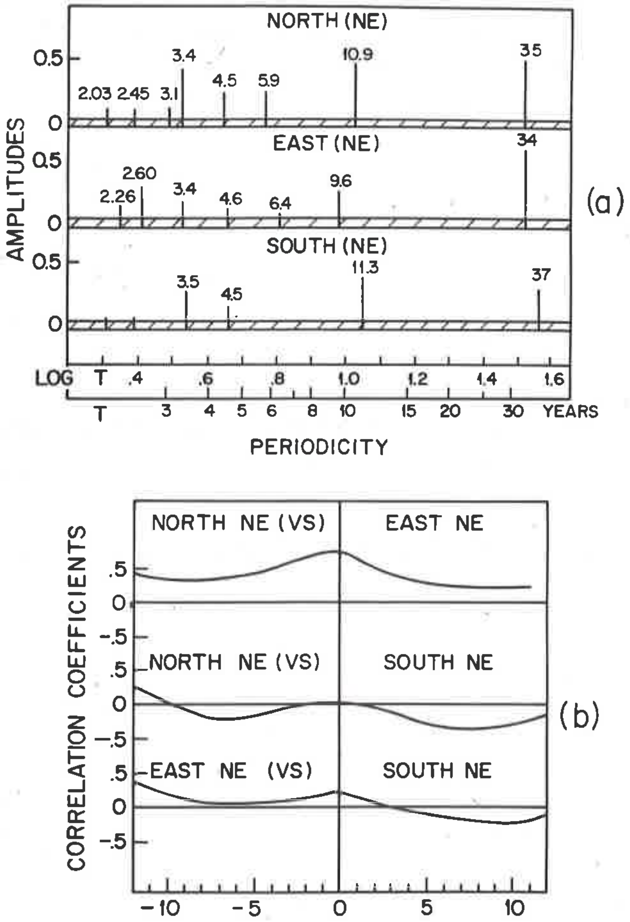

Figure 9 - (a) Spectra of the northern, eastern and southern NE average rainfall series for 1951-1985. The hatched portion indicates 2s (a priori) limits and (b) cross-correlations between northern, eastern and southern NE rainfalls.

Figura 9 *- (a) Espectro das séries médias da precipitação pluviométrica no período de 1951-1985, para as regiões norte, leste e sul do NE brasileiro. As porções hachuradas indicam os limites 2s; (b) Correlações cruzadas entre as precipitações pluviométricas do norte, leste e sul do NE brasileiro.*

thick line) and the difference (12-36). Some peaks are clearly recognizable and similar for all the three locations but others are not clear or similar. Fig. 9(a) shows the spectra (amplitude estimates) for the periodicities in the 12 monthly running mean. For QBO, northern NE has small periodicities at 2.03, 2.45 years, the eastern NE region has strong periodicities at 2.26 and 2.60 years, and southern NE has no significant QBO. Periodicities 3.5 and 4.5 years are prominent everywhere, while periodicities in the range (9.6-11.3) are also present in the three regions. The larger periodicities (34, 35, 37 years) in a 35 years sample are not reliable and are, probably indicative of long-term trends, visible in the thick line (3-year mean) plots of Fig. 5.

Table 3 shows the periodicities significant above a 4s (in reality, 2s) level, for the period 1951-1985, for the rainfall series at individual locations and their 3 groups.

The overall lags or leads can be obtained by a cross-correlation analysis. Fig. 9(b) top shows the results for

	Periodicity ranges (years)					
Rainfall series (1951-1985)	2.00- 2.30	2.31-2.60	2.6 - 3.0	3.0 - 4.0	4.0 - 8.0	7.0-14.0
Acaraú				3.5	4.8, 5.8	11.7
Fortaleza				3.5	5.1	11.5
Pendência				3.5	6.0	10.7
João Câmara				3.3	4.2	
Canguaretama		2.59	2.96	3.5		10.0
Recife					7.1	
Macció						14.6
Aracajú				3.4		9.9
Alagoinhas				3.6	6.1	9.0
Ilhéus				3.5		9.4
Condeúba				3.4	5.8	11.3
Januária					7.0	12.6
North NE BR	2.03	2.45		3.4	4.5, 5.9	10.9
East NE BR	2.26	2.60		3.4		9.6
South NE BR				3.5	4.5	11.3

Table 3 - Periodicities significant at a 95% confidence level, for 1951-1985, for rainfall at various locations.

***Tabela 3** - Periodicidades significativas ao nível de confiança de 95%, para 1951-1985, para a precipitação pluviométrica em várias localidades.*

rainfalls of northern NE versus eastern NE and indicates reasonably good correlation (exceeding 0.5) at zero lag. But correlations of northern and eastern NE with southern NE are very low, indicating that rainfall characteristics of southern NE are very different from those of northern or eastern NE Brazil, as was evident in Fig. 9(a) also.

Fig. 10 shows the cross-correlations of the three NE Brazil rainfall series (a) N-NE, (b) E-NE, (c) S-NE versus 50mb wind, T-D and EEP-SST in rows 1, 2, 3, Atlantic SST parameters N, S, (N+S) (N-S) in rows 4, 5, 6, 7 and NE Brazilian coast SST and WIND STRESS in rows 8, 9. The full lines show correlations between 12 monthly running means and thus, include effects of QBO, QTO and all other larger periodicities including long-term trends. To know the relationships for QBO, QTO only, and the (12-36) values of all the parameters were used for correlation. The dashed lines in Fig. 10 represent such correlations. The results are summarized in the Conclusions.

CONCLUSIONS

Our results are contained mainly in Fig. 6-10 and the main conclusions are as follows:

1) Analysis of the 12 monthly running means centered 3 months apart (4 values per year) by Maximum Entropy Spectral Analysis reveals periodicities much more accurately than the use of one value per year. For data from 1951 onwards, results are as follows (see Fig. 6, 7, 9, 10).

2) In the QBO region, only 50mb wind had very prominent periodicities, the largest one at 2.33 years, a smaller one (~2/3 magnitude) at 2.64 years and a still smaller one at ~2.00 years.

(T-D) and EEP-SST had small QBO at (2.05-2.10) and 2.57 years.

N (North) and S (South) Atlantic SST had QBO at (2.10-2.16) years. (N+S) and (N-S) showed an additional peak at (2.64-2.70) years which was seen in the Wind Stress also at NE Brazil coast.

The NE Brazil coastal SST showed a peak at 2.29 years while Wind Stress showed 2.20 years. Thus, whereas (T-D) or Atlantic SST did not show any peak near the prominent peak of 50mb wind at 2.33 years, the NE coastal Wind Stress did show a peak at 2.29 years.

In the NE rainfall series (Fig. 9), small QBO was observed at 2.03 and 2.45 years in northern NE, 2.26 and 2.60 years in eastern NE and no significant QBO in southern NE rainfall. None of these tally exactly with the 50mb wind peaks (~2.00, *2.33* and 2.64 years); but some connection may exist between 50mb wind and terrestrial phenomena like (T-D), EEP-SST and the various rainfalls through QBO near 2.00 and 2.50 years. Gray et al. (1992) have described hypothetical mechanisms by which QBO of lower stratosphere zonal winds alters the distribution of intense deep convective activity throughout the tropical west Pacific. Conversely, Geller & Zhang (1991) and Geller et al. (1997) explore a mechanism by which SST variations modulate tropical wave activity, which may force stratospheric zonal flow with the same period as the QBO of SST.

3) In the QTO region, 50mb wind had a small peak at 3.2 years, NE Brazil coastal wind stress had a peak at 3.3 years while (T-D), EEP-SST, Atlantic N, S, (N+S), (N-S) and NE Brazil coastal SST had peaks in (3.5-3.8) year range. In NE rainfall, all the three regions (northern, eastern, southern) had prominent peaks at (3.4-3.5) years while northern NE had a small peak at 3.1 years. Thus, ~3.5 years seems to be a prominent periodicity pervading all the terrestrial parameters. Surprisingly, this periodicity is completely missing in the analysis of Hastenrath and Kaczmarczyk (1990) who mention 2.5, 5, 10 and 13-21 years for NE Brazil rainfall for the period 1921-1972. Chu

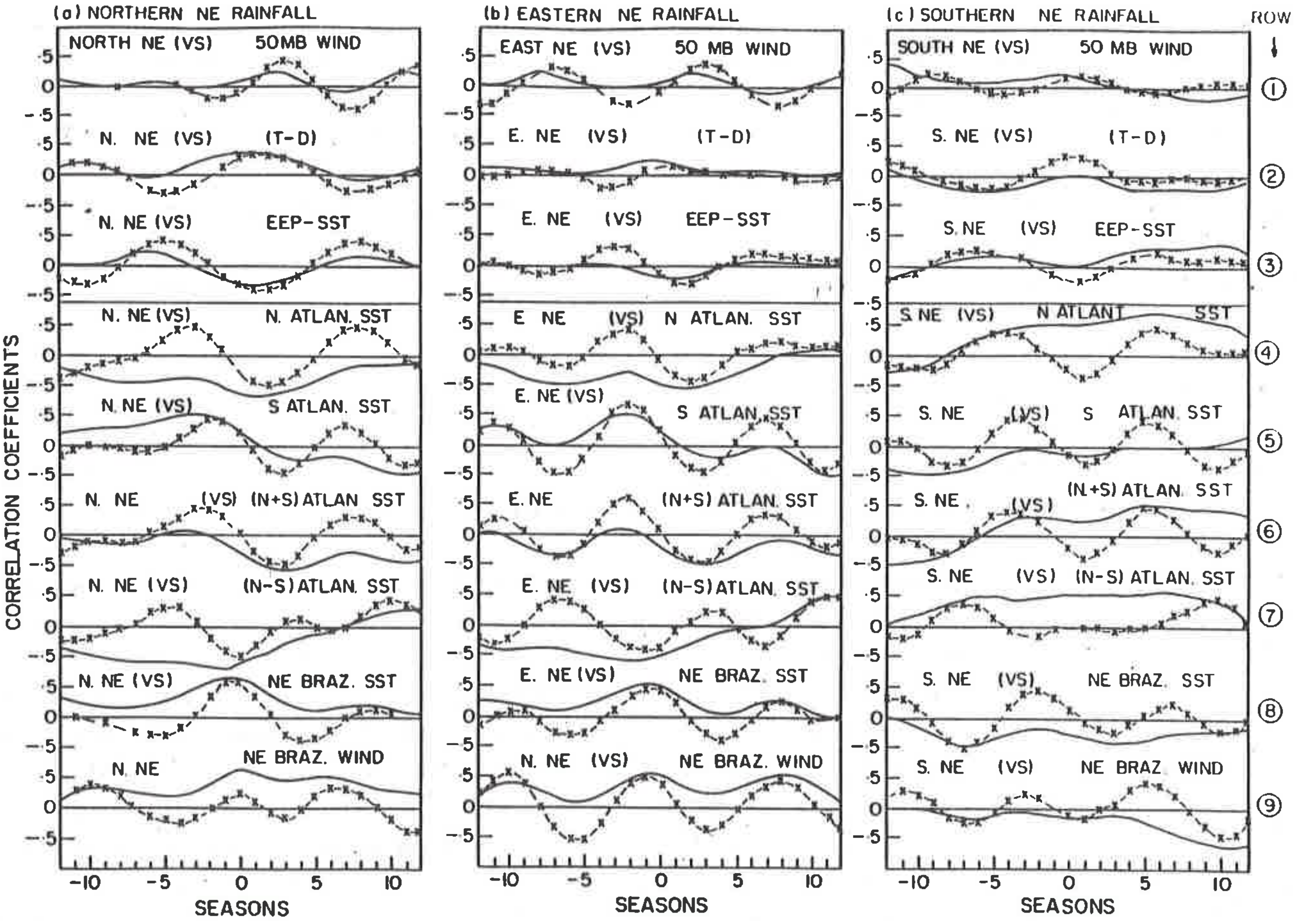

Figure 10 - Cross-correltions of 12 monthly running means (full lines) and (12-36) values (dashed lines) of (a) northern NE; (b) eastern NE; (c) southern NE rainfalls, with 50mb wind (row 1), (T-D) (row 2), EEP-SST (row 3), Atlantic SST, N, S, N+S, N-S (rows 4, 5, 6, 7) and NE Brazilian coast, SST (row 8) and Wind Stress (row 9).

***Figura 10** - Correlações cruzadas das 12 médias móveis mensais (linha cheia) e dos valores (12-36) (linhas tracejadas) de: (a) norte; (b) leste; (c) sul do NE, para as precipitações pluviométricas, com vento de 50 mb (linha 1), (T-D) (linha 2), EEP-SST (linha 3), SST Atlântico, N, S, N+S, N-S (linhas 4, 5, 6 e 7) e SST da costa do NE brasileiro (linha 8) e tensão do vento (linha 9).*

(1984) also does not mention 3.5 years (only ~2.2-2.4 years and 4.5-4.9 years are mentioned); but in Fig. 4 of Chu (1984), small peaks near 3.5 years are seen. It is likely that this period has come into prominence only recently (after 1974).

4) Peaks in the (4.5-5.0) years band are seen prominently in almost all parameters, including NE Brazil rainfall in all the three regions, in agreement with 5 years mentioned by Hastenrath & Kaczmarczyk (1989) for NE Brazil and (4.5-4.9) years mentioned by Chu (1984) for both northern and southern NE rainfall. Earlier, Kousky & Chu (1978) mentioned a broad band 3-5 years.

5) Peaks near 5.5 years are seen in southern Atlantic SST (also reflected in N+S and N-S) and NE Brazilian coastal Wind Stress and are reflected in Fortaleza rainfall (Fig. 6); but in northern NE rainfall (Fig. 9), this peak shifts to 5.9 years, in eastern NE rainfall to 6.4 years, and is missing in southern NE rainfall. In Fig. 4 of Chu (1984), there is an indication of two peaks near 5.0 and 5.5 years, though Chu has mentioned this band only as (4.5-4.9) years.

6) Peaks at 9.5, 9.6, 9.8, 10.5, 10.9, 11.3, 12.3, 12.5, 13.9 (9.5-13.9 years) exist in many parameters. Hastenrath & Kaczmarczyk (1981) mention these as 10 and 13-21 years, while Chu (1984) mentions these as (12.7-14.9) years, though Fig. 4 of Chu (1984) shows two peaks, one near 10 and another near 16 years. Earlier, Kousky & Chu (1978) had identified a broad band at (10-20) years.

7) Regarding cross-correlations, northern and eastern NE rainfall seem to be fairly well correlated (0.75) with each other (Fig. 9b) while southern NE rainfall is poorly correlated (0.2 or less) with northern and eastern NE rainfall.

These results are in general agreement with those of Kousky & Chu (1978), Hastenrath & Kaczmarczyk (1990), Chu (1983, 1984), Rao et al. (1993) and, besides giving finer details of the periodicities involved, indicate that at least for the northern and eastern NE rainfall, the Atlantic N and S, SST and winds in S. Atlantic are the most important parameters. The relationship becomes more intense when parameters nearer to NE Brazilian coast are considered; but then the advantage of antecedence is lost. The role of (T-D) or EEP-SST or 50mb wind seems to be comparatively negligible.

For studying the dynamics of droughts in NE Brazil, Moura & Shukla (1981) conducted numerical experiments with a General Circulation Model and obtained satisfactory results. The role of 50mb wind is not yet theoretically explored for NE Brazil but the observed relationship is weak. For floods and droughts in the Indian monsoon, Khandekar (1996) proposed a conceptual large-scale atmospheric flow model, involving the Walker circulation in the equatorial zonal plane associated with El Nino, the tropical easterly jet stream at 150mb centered around 12°N, easterly/westerly phases of the QBO at 50mb and Eurasian winter snow cover. For NE Brazil, a similar study is warranted.

The characteristics of northern NE and eastern NE rainfall are almost similar but differ considerably from those of southern NE rainfall for which Chu (1984) mentions additional relationships with winds and SST of southeast coast of Brazil (50°-10°W, 20°-30°S) or, in general, cold fronts of the Southern Hemisphere (Kousky & Chu, 1978; Kousky, 1979; Chu, 1983).

Overall, we are inclined to believe that the QBO, QTO characteristics of northeast Brazil rainfall are related mainly to the characteristics of the Atlantic parameters, including those near the NE Brazil coast, though rainfalls in different parts of NE Brazil may be affected in different proportions by the different parameters.

ACKNOWLEDGEMENTS

Thanks are due to CPTEC/INPE for providing the rainfall data and to Drs. Servain and Vianna for NE Brazil coastal data. This work was partially supported by FNDCT Brazil under contract FINEP-537/CT.

REFERENCES

ACEITUNO, P. - 1988 - On the functioning of the Southern Oscillation in the South American sector. Part I: Surface Climate. Mon. Wea. Rev., **116**: 505-524.

ANGELL, J. K. - 1981 - Comparison of variations in atmospheric quantities with sea surface temperature variations in the equatorial eastern Pacific. Mon. Wea. Rev., **109**: 230-243.

ANGELL, J. K. & KORSHOVER, J. - 1962 - The biennial wind and temperature oscillations of the equatorial stratosphere and their possible extension to higher latitudes. Mon. Wea. Rev. **90**: 122-132.

BEVINGTON, P. R. - 1969 - Data reduction and error analysis for the Physical Sciences. McGraw Hill, New York, pp. 164-176.

BHALME, H. N., RAHALKAR, S. S. & SIKDAR, A. B. - 1987 - Tropical quasi-biennial oscillation of the 10mb wind and Indian monsoon rainfall - Implications for forecasting. J. Climatol., 7: 345-358.

BLACKMAN, R. B. & TUKEY, J. W. - 1958 - The measurement of power spectra. Dover, New York, pp. 190.

BURG, J. P. - 1967 - Maximum entropy spectral analysis. Paper presented at the 37th Meeting, Society of Exploration Geophysics, Oklahoma City, October.

CHU, P. S. - 1983 - Diagnostic studies of rainfall anomalies in Northeast Brazil.. Mon. Wea. Rev. **111**: 1665-1664.

CHU, P. S. - 1984 - Time and space variability of rainfall and surface circulation in the northeast Brazil-tropical Atlantic sector. J. Meteor. Soc. Japan, **62**: 363-370.

CHUNG, J. C. - 1982 - Correlations between the tropical

Atlantic trade winds and precipitation in NE Brazil. J. Climatol., **2**: 35-46.

DESER, C. & WALLACE, J. M. - 1987 - El Nino events and their relation to the Southern Oscillation: 1925-1986. J. Geophysics. Res., **92**: 14189-14196.

GELLER, M.A. & ZHANG, M. - 1991 - Sea surface temperatures, equatorial waves, and the quasi-biennial oscillation, Abstract QB-5, Symp. on Middle Atmos. Sci., Kyoto.

GELLER, M. A., SHEN, W., ZHANG, M. & TAN, W. W. - 1997 - Calculations of the stratospheric quasi-biennial oscillation for time-varying wave forcing. J. Atmos. Sci., **54**: 883-894.

GRAY, W. M., SHEAFFER, J. D. & KNAFF, J. A. - 1992 - Hypothesized mechanism for stratospheric QBO influence on ENSO variability. Geophys. Res. Lett., **19**: 107-110.

HASTENRATH, S. - 1990 - Prediction of northeast Brazil rainfall anomalies. J. Climate **3**: 893-904.

HASTENRATH, S. & HELLER, L. - 1977 - Dynamics of climate hazards in northeast Brazil. Quart. J. Roy. Meteor. Soc., **103**: 77-92.

HASTENRATH, S. & KACZMARCZYK, E. B. - 1981 - On spectra and coherence of tropical climate anomalies., Tellus **33**: 453-462.

HASTENRATH, S., WU M-C & CHU, P-S. - 1984 - Towards the monitoring and prediction of northeast Brazil droughts. Quart. J. Roy. Meteor. Soc., **110**: 411-425.

KANE, R. P. - 1995 - Quasi-biennial and quasi-triennial oscillations in the summer monsoon rainfall of the meteorological subdivisions of India. Mon. Wea. Rev., **123**: 1178-1184.

KANE, R. P. - 1996 - Interannual variability of precipitable water. Ann. Geophysicae, **14**: 464-467.

KANE, R. P. & GOBBI, D. - 1995 - Interannual variability of United States cloudiness. Ann. Geophysicae, **13**: 660-665.

KANE, R. P. & TRIVEDI, N. B. - 1982 - Comparison of Maximum Entropy Spectral Analysis (MESA) and Least-Squares Linear Prediction (LSLP) methods for some artificial samples. Geophysics, **47**: 1731-1736.

KANE, R. P. & TRIVEDI, N. B. - 1988 - Spectral characteristics of the annual rainfall series for northeast Brazil. Climatic Change, **13**: 317-336.

KHANDEKAR, M. L. - 1996 - El Nino/Southern Oscillation, Indian monsoon and world grain yields - A synthesis. In: Advances in Natural and Technological Hazards. (Eds. M.I. El-Sabh, S. Venkatesh, H. Denis and T.S. Murty), Kluwer Academic Publishers, July 1996, pp. 79-96.

KOUSKY, V. E. - 1979 - Frontal influences on Northeast Brazil. Mon. Wea. Rev., **107**: 1140-1153.

KOUSKY, V. E. & CHU, P. S. - 1978 - Fluctuations in annual rainfall for northeast Brazil. J. Meteor. Soc. Japan, **56**: 457-465.

LANDSBERG, H. E. & KAYLOR, R. E. - 1976 - Spectral analysis of long meteorological series. J. Interdisciplinary Cycle Res., **7**: 237-243.

LANDSBERG, H. E., MITCHELL, J. M., CRUTCHER, H. L. & QUINTER, F. T. - 1963 - Surface signs of the biennial atmospheric pulse. Mon. Wea. Rev., **91**: 549-556.

LINDZEN, R. S. & HOLTON, J. R. - 1968 - A theory of the quasi-biennial oscillation. J. Atmos. Sci., **25**: 1095-1107.

MARKHAM, C. G. - 1974 - Apparent periodicities in rainfall at Fortaleza, CE, Brazil. J. Appl. Met., **13**: 176-179.

MARKHAM, C. G. & MCLAIN, D. R. - 1977 - Sea surface temperature related to rain in Ceara, Northeast Brazil. Nature, **265**: 320-323.

MOURA, A. D. & SHUKLA, J. - 1981 - On the dynamics of droughts in northeast Brazil: Observations, theory and numerical experiments with a General Circulation Model. J. Atmos. Sci., **38**: 2653-2675.

NAMIAS, J. - 1977 - Influence of northern hemispheric general circulation on drought in northeast Brazil. Tellus, **24**: 336-342.

NAUJOKAT, B. - 1986 - An update of the observed quasi-biennial oscillation of the stratospheric winds over the tropics. J. Atmos. Sci., **43**: 1873-1877.

PARKER, D.E. - 1983 - Documentation of a Southern Oscillation index. Meteorol. Mag., **112**: 184-188.

PLUMB, R. A. & BELL, R. C. - 1982 - A model of the quasi-biennial oscillation on an equatorial beta-plane. Quart. J. Roy. Meteor. Soc., **108**: 335-352.

QUINN, W. H., ZOPF, D. O., SHORT, K. S. & KUO YANG, R. T. W. - 1978 - Historical trends and statistics of the Southern Oscillation, El Nino and Indonesian Droughts. Fish. Bull., **76**: 663-678.

QUINN, W. H., NEAL, V. T. & ANTUNEZ DE

MAYOLO, S. E. - 1987 - El Nino occurrences over the past four and a half centuries. J. Geophys. Res., **92**: 14449-14461.

RAMOS, R. P. L. - 1975 - Precipitation characteristics in the northeast Brazil dry region, J. Geophys. Res. ,**80**: 1665-1678.

RAO, V. B., DE LIMA, M. C. & FRANCHITO, S. H. - 1993 - Seasonal and interannual variations of rainfall over eastern northeast Brazil. J. Climate, **6**: 1754-1763.

RASMUSSON, E. M., WANG, X. & ROPELEWSKI, C. F. - 1990 - The biennial component of ENSO variability. J. Marine Systems, **1**: 71-96.

REED, R. J., CAMPBELL, W. J., RASMUSSON, L. A. & ROGERS, D. J. - 1961 - Evidence of a downward propagating annual wind reversal in the equatorial stratosphere. J. Geophys. Res., **66**: 813-818.

ROGERS, J. C. - 1988 - Precipitation variability over the Caribbean and tropical Americas associated with the Southern Oscillation. J. Climate, **1**: 172-182.

ROPELEWSKI, C. F. & HALPERT, M. S. - 1987 - Global and regional scale precipitation patterns associated with El Nino/Southern oscillation. Mon. Wea. Rev., **115**: 1606-1626.

SERVAIN, J. - 1991 - Simple climate indices for the tropical Atlantic ocean and some applications. J. Geophys. Res., **96**: 15137-15146.

SERVAIN, J. & SEVA, M. - 1987 - On relationships between tropical Atlantic sea surface temperature, wind stress and regional precipitation indices: 1964-1984. Ocean Air Interac., **1**: 183-190.

SPERBER, K. R. & HAMEED, S. - 1993 - Phase locking of nordeste precipitation with sea surface temperatures. Geophys. Res. Lett., **20**: 113-116.

THAPLIYAL, V. - 1984 - Prediction of Indian droughts with lower stratospheric winds. Mausam, **35**: 367-374.

ULRYCH, T. J. & BISHOP, T. N. - 1975 - Maximum Entropy Spectral Analysis and autoregressive decomposition. Rev. Geophys., **13**: 183-200.

VENNE, D. E. & DARTT, D. G. - 1990 - An examination of possible solar cycle - QBO effects in the northern hemisphere troposphere. J. Climate, **3**: 272-281.

VERYARD, R. G. & EBDON, R. A. - 1961 - Fluctuations in tropical stratospheric winds. Meteor. Mag., **90**: 125-143.

XAVIER, T., DE MA, B. & XAVIER, A. F. S. - 1997 - Papel da componente meridional do vento na costa do nordeste para a previsão da chuva no Estado do Ceará. Anais do Simpósio Brasileiro de Recursos Hídricos, **1**: 537-543.

YAMAZAKI, Y. & RAO, V. B. - 1977 - Tropical cloudiness over the south Atlantic Ocean. J. Meteor. Soc. Japan, **55**: 205-207.

Submetido em: 03/02/98
Revisado pelo autor (es): 12/08/98
Aceito em: 18/08/98

NOTE ABOUT THE AUTHOR
NOTA SOBRE O AUTOR

Dr. Rajaram Purushottam Kane was born in India on 12th November 1926. His earlier education was in Gwalior, Madhya Pradesh, India. He received his B.Sc. in 1944 from Agra University, India and M.Sc. in 1946 from Banaras Hindu University, India. He joined the Physical Research Laboratory (PRL), Ahmedabad, India as a post-graduate student in 1948 and received his Ph.D. on "Time-variation of Cosmic Ray Intensity near Geomagnetic Equator" from Bombay University, India in 1953. During 1953-54, he was awarded a Fulbright & Smith-Mundt Fellowship to work with Prof. J. A. Simpson at the Institute of Nuclear Studies, University of Chicago, Chicago, USA. During 1955-56, he was a Senior Fellow of the National Institute of Science of India at PRL and later, till 1978, he was on the PRL Faculty. Since May, 1978, he is at INPE (Instituto Nacional de Pesquisas Espaciais) at São José dos Campos, SP, Brazil, working in the fields of Geomagnetism and Aeronomy, Solar Physics, Rainfall studies etc.