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RELATIONSHIP BETWEEN EL NIÑO TIMINGS AND RAINFALL EXTREMES IN NE BRAZIL, SÃO PAULO CITY AND SOUTH BRAZIL

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ABSTRACT

El Niños are believed to be associated with droughts in NE Brazil and excess rains in south Brazil. However, some El Niños do not show such a relationship. Since El Niños can commence in any month during the year, El Niños starting after the main rainy season or terminating before the main rainy season may not be effective. In this communication, the timings of El Niños vis a vis rainfall are examined. For NE Brazil near Fortaleza, the main rainy season is MAM (March, April, May). It was noticed, that during 1940-1992, there were 11 El Niño events that had commencements in Jan.-Feb.-Mar., suitable for resulting in droughts in MAM; but only 4 resulted in droughts. Thus, the El Niño relationship (expected droughts) in the main rainy season of NE Brazil was very poor. *In contrast, the pre-rainy season months DJF seemed to show significant rain deficits, in 9 out of the 11 events*. The reason for this needs further study. In São Paulo City, the El Niño effects were erratic. Normal as well excess or deficit rainfalls occurred, though a slight bias for excess rains during local spring (ASON months) was indicated. In south Brazil, only El Niños active during the latter half of the calendar year were effective in causing excess rains. Overall, the El Niño-rainfall relationship was poor, and effects due to other factors (Atlantic sea surface temperatures, cold fronts from the Antarctic, etc.) are probably more important, as is already reported in the literature.
Key-words: El Niño, NE Brazil rainfall.

RESUMO: RELAÇAO ENTRE A DURAÇÃO DO EL NIÑO E EXTREMOS PLUVIOMÉTRICOS NO NORDESTE, CIDADE DE SÃO PAULO E SUL DO BRASIL

Acredita-se que os fenômenos El Niños estejam associados com secas no NE e excesso de chuvas no Sul do Brasil. Contudo alguns El Niños não mostram tal relação. Desde que os El Niños podem começar em qualquer mês durante o ano, El Niños que comecem após a principal estação chuvosa ou terminem antes da principal estação chuvosa podem não ser efetivos. Nesta comunicação, os tempos de início de El Niños em relação à precipitação são examinados. Para o NE do Brasil, próximo a Fortaleza, a principal estação chuvosa é MAM (março, abril, maio). Foi notado que durante 1940-1992 houve 11 eventos El Niños que começaram em jan.- fev.-mar., o que é conveniente para resultar em secas em MAM, mas apenas 4 resultaram em secas. Assim, a relação com os El Niños (secas esperadas) na principal estação chuvosa para o NE do Brasil foram muito pobres. Em contraste, os meses da estação pré-chuvosa DJF pareceram mostrar significantes déficits de precipitação em 9 entre os 11 eventos. A razão para isto necessita de estudos adicionais. Em São Paulo, o efeito do El Niño foi errático. Ocorreram períodos normais, bem como excesso ou déficit de precipitação, embora houvesse uma leve tendência para excesso de chuvas durante a primavera local (meses ASON). No Sul do Brasil, apenas os El Niños ativos durante a última metade do ano foram efetivos em causar excesso de chuvas. Em média, a relação El Niño-precipitação foi pobre, e efeitos devidos a outros fatores (temperaturas da superfície do Atlântico, frentes frias vindas da Antártica, etc.) são provavelmente mais importantes, como já relatado na literatura.
Palavras-chave: El Niño, chuvas no NE do Brasil.

1. INTRODUCTION

Along the coast of Peru-Ecuador in South America, there is an ocean current called Peru or Humboldt current. Hushke (1959) defined El Niño (The Child) as a warming of this ocean current, so called because it generally developes near Christmas, the birth of Jesus Christ. In some years, the current may extend southward along the coast of Peru to latitude 12oS, killing plankton and fish in thc coastal waters. Quinn et al. (1978, 1987) determined the occurrence of El Niño events on the basis of the disruption of fishery, hydrological data, sea-surface temperature and rainfall along and near the Peru-Ecuador coast, defining intensities based on the positive sea-surface temperature anomalies along the coast as: Strong, in excess of 3oC; Moderate, 2.0o-3.0oC; Weak, 1.0o-2.0oC.

It is popularly believed that El Niños are associated with droughts in NE Brazil. In the past, severe droughts occurred there during the El Niño events of 1877-78, 1891, 1900, 1907, 1932, 1941, 1958, 1983. However, the number of El Niños is much larger (46 strong and moderate events during 1849-1992) and not all were associated with droughts in NE Brazil (Kane, 1992, 1997). Though El Niños are believed to mature near about Christmas, not all necessarily do so. As mentioned by Deser and Wallace (1987), some occur in the early part of the calendar year, some later. For rainfall regimes having maximum rain during the early part of the year (e.g., March, April, May, MAM, in NE Brazil), El Niño starting late in the year should not have any influence. In this communication, the timings of the El Niños are examined to check whether some of these events proved ineffective because of such delayed commencements. A similar analysis is conducted for the rainfall at São Paulo city (southeast Brazil) and at some locations in south Brazil.

2. DATA

For classification of years of ENSO (El Niño/ Southern Oscillation) phenomenon, El Niño data were obtained from Quinn et al. (1978, 1987), SO index from Wright (1977, 1984), and Parker (1983) and equatorial eastern Pacific SST data from Angell (1981, and further private communication) and Wright (1984), who has given a Wright Index referring to SST anomalies in the region (6oN-10oS, 180o-90oW). For rainfall, data for Fortaleza were obtained from SUDENE (Superintendência do Desenvolvimento do Nordeste, Brazil) publication "Dados Pluviométricos Mensais". Also, for a restricted region (3o-8oS, 36o-41oW) in Northeast Brazil, Hastenrath (1990) prepared a series (March-September rainfall) combining data of 27 stations. The locations of these 27 stations are shown by crosses in Fig. 1, and the Hastenrath series will be referred to henceforth as HT. For the eastern northeast (ENE) Brazil (6o-11oS, 35o-40oW), Rao et al. (1993) obtained a series (Apr.-July rainfall) combining data from 63 stations. These 63 stations are shown by dots in Fig. 1 and their series will be referred to henceforth as R. Data processing details are given in the respective publications and basically, rainfall at each location is expressed as fractions of its standard deviation (normalized units) and the standardized values are averaged for all stations in each group. Outside the northeast region, annual rainfall data were supplied by CENACLI (Centro Nacional de Análises Climáticas, Brazil) for São Paulo (SP, Southeast Brazil) and Porto Alegre, Bagé and Nova Palmira (south Brazil). Some updated values were supplied by Dra. Alice Grimm - UFPR.

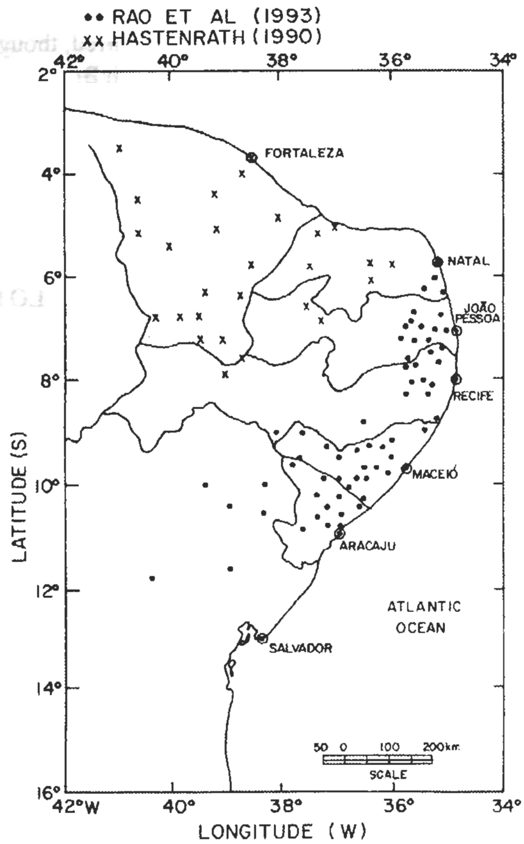

Figura 1 - Map of Northeast Brazil, showing the locations of the stations used by Hastenrath (1990) (crosses) and Rao et al. (1993) (dots).

The rainfalls in NE Brazil are reported to have El Niño effects opposite to those of south Brazil, a sort of seesaw effect, droughts in NE associated with excess rainfall in the south, or vice versa. This aspect is specially examined and for this, more than one group or locations in these regions (NE Brazil and south Brazil) are considered. Just to check what happens in between, rainfall at only one location (São Paulo City) is examined, as reliable data for this location only were available to us, updated by courtesy of Dr. Pedro Dias. These data may not be representative of the whole state of São Paulo. For NE Brazil and for São Paulo, seasonal data were available; but for south Brazil, only annual values were immediately available. However, in that region, major rainfall seems to occur in the latter half of the calendar year. So, the annual values would represent mainly the July-December rainfall.

For commencement and evolution of the El Niño, the SST (sea-surface temperature) anomalies at Puerto Chicama (Peru coast, 8oS, 80oW) are used. These are available since 1925 (Deser and Wallace, 1987 and private communication from Dr. Todd Mitchell). Since 1950, CPC (Climate Prediction Center of NOAA's National Centers for Environmental Prediction) Climate Diagnostic Bulletins give average monthly temperatures in four geographical regions, Niño 1+2 near the Peru-Ecuador coast (0o-10oS, 90oW-80oW), Niño 3 at (5oN-5oS, 150oW-90oW) and Niño 4 at (5oN-5oS, 160oE-150oW). Trenberth (1997) gives similar values for Niño 3.4 at (5oN-5oS, 170oW-120oW). Among these, Niño 1+2 region temperature variations match those of Puerto Chicama SST very well, except that the Puerto Chicama SST anomalies are larger by about a factor of 2. Also, the anomaly evolves and fades along the eastern Pacific almost at the same time (within a month or two) as the Puerto Chicama anomaly. Two examples are given below (threshold ~0.4oC):

The 1957-58 event	Puerto Chicama	Feb. 1957-July 1958,	Duration 18 months
	Niño 1+2	Feb. 1957-July 1958	18
	Niño 3.4	Apr. 1957-Aug. 1958	17
	Wright Index	Mar. 1957-Aug. 1958	18

The 1972-73 event	Puerto Chicama	Feb. 1972-Feb. 1973	Duration 13 months
	Niño 1+2	Feb. 1972-Feb. 1973	13
	Niño 3.4	Mar. 1972-Mar. 1973	13
	Wright Index	Apr. 1972-Mar. 1973	12

The only glaring exception was the 1982-83 event, when Puerto Chicama showed commencement as late as in October 1982, while other regions showed commencements much earlier, for example, Niño 1+2 in July 1982; Niño 3.4 in May 1982; Wright Index (Wright, 1984) in May 1982. Quiroz (1983) mentioned that the 1982-83 El Niño event was of extraordinary climate anomalies, unlike most of the earlier El Niño events. The Wright Index (Wright, 1984) refers to the SST anomalies of the region (6oN-10oS, 180O-90oW), roughly the same as Niño 3.4. In what follows, only Puerto Chicama SST is used for locating the commencements and durations of the El Niño event.

3. RESULTS

A. Puerto Chicama SST

From the monthly values of SST at Puerto Chicama, an average seasonal pattern (climatology, average values for January, February etc.) was determined. These monthly averages were subtracted from the original values and the residues were used as deseasoned anomalies. Fig. 2(a) shows a plot of the deseasoned monthly values of Puerto Chicama SST for 4-year intervals, during which the second year has the El Niño commencement. All the events in Fig. 2(a) are strong. Some moderate events are shown in Fig. 2(b). An event

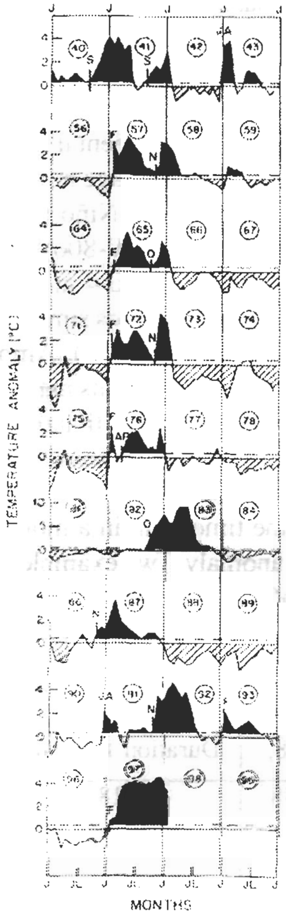

Fig. 2(a)

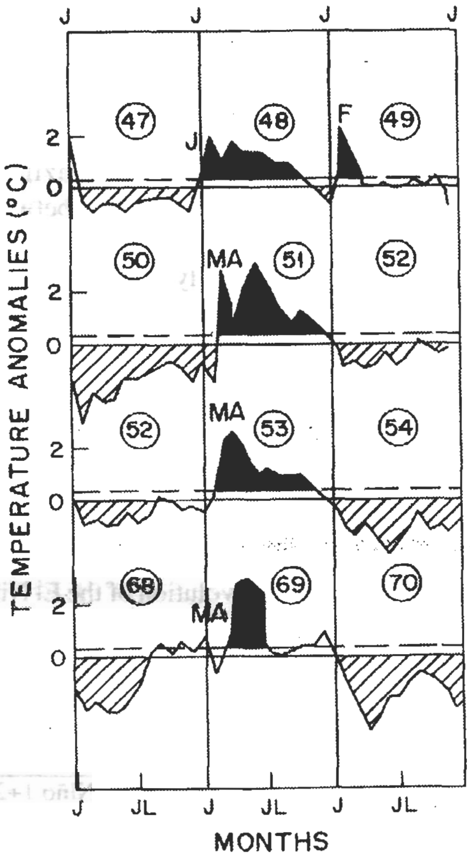

Fig. 2(b)

Figura 2(a) - Evolution of temperature anomalies (deviations from the average seasonal pattern) at Puerto Chicama (8oS, 80oW) on Peru coast, as indicator of some strong El Niño events, for four successive years (as marked). Positive anomalies exceeding 0.4oC are painted black and negative anomalies are shown hatched. For the 1997 event bottom plot), Puerto Chicama values were not available and Niño 1+2 data are used.
(b) Same as (a), for four moderate El Niño events.

is considered as started when the temperature anomaly exceeds 0.4oC, a criterion introduced by Trenberth (1997). The interval of positive anomaly is painted black. Often, there are complex events with strong positive anomalies lasting for a few months, then disappearing or reducing for a month or two and reappearing to last for several more months, spilling into the next year, creating double events (1957-58 etc.). El Niño commencements occurred in different months: 1943, 1948 in January; 1949, 1957-58, 1965-66, 1972-73, 1976, 1993, 1997 in February; 1951, 1953, 1969 in March; (no commencements in April, May, June, July, August); 1940 in September; 1982 in October and 1986 in November. In recent times, an event started in January 1991 (Fig. 2a) but disappeared quickly and reappeared late in November 1991 and continued in 1992.

B. Fortaleza Rainfalls

In Northeast Brazil, Fortaleza (3o42'S, 38o31'W), Ceará has the longest rainfall series (1849 onwards). Here, only data for 1933 onwards are used as we had São Paulo data only since then and also, Puerto Chicama SST data are available only since 1925. Fig. 3 shows the climatology of Fortaleza rainfall. The maximum rainfall is in March, April, May and the minimum in September, October, November. Hence, rainfalls were considered for successive trimesters DJF, MAM, JJA, SON where the major rainfall (main rainy season) is in MAM. However, all the other seasons were also considered, to check whether El Niño caused any rainfall excesses or deficits in the off-seasons. For the Fortaleza series (one value per year) of each of these trimesters, mean and the standard deviation were calculated and value of every

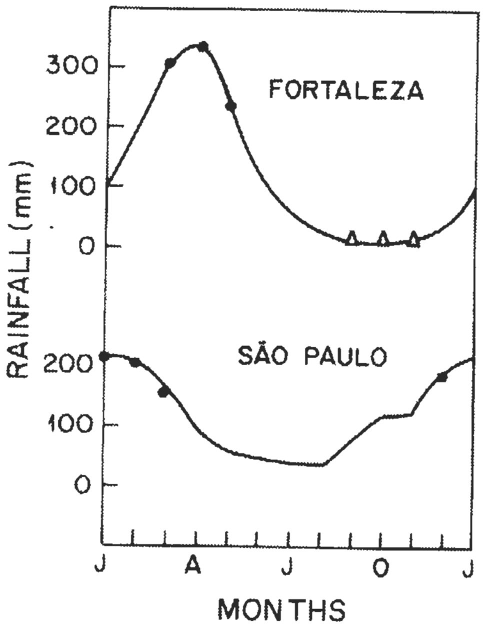

Fig. 3

Figura 3 - The average monthly rainfall (climatology) at Fortaleza, Ceará (NE Brazil) and at São Paulo City (Southeast Brazil).

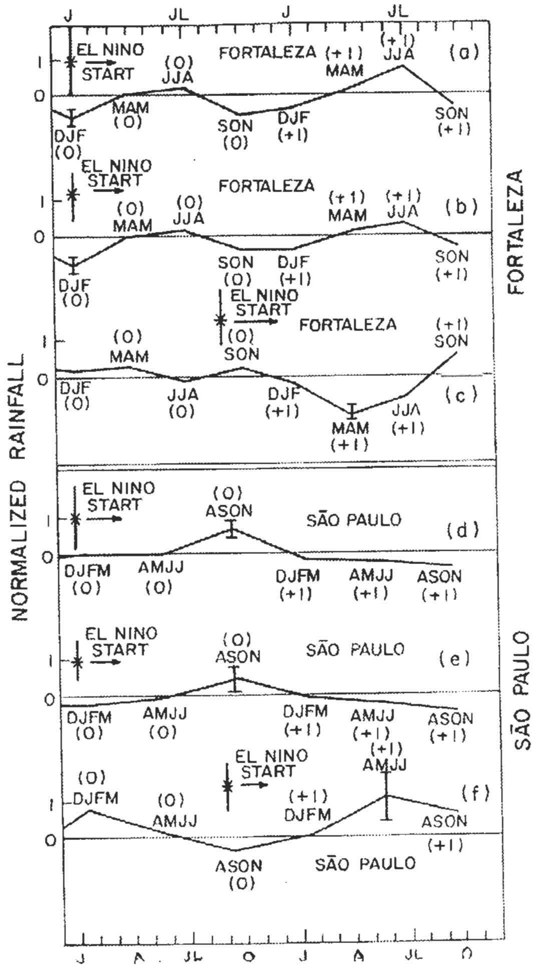

Fig. 4

Figura 4 - Average normalized rainfall deviations at Fortaleza (upper half) and at São Paulo (lower half) for two consecutive years (0) and (+1) wherein the El Niño commenced (marked with an *) in the first (0) year. In each half (upper and lower), the plots (a, d) show averages for the 8 El Niño events commencing in January, February. Plots (b, e) show averages for 11 events commencing in January, February, March. and the plots (c, f) show averages for 4 events commencing in September, October, November. For Fortaleza, the successive points are average rainfall deviations for DJF (0), MAM (0), JJA (0), SON (0), DJF (+1), MAM (+1), JJA (+1), SON (+1). For São Paulo, the successive points are average rainfall deviations for DJFM (0), AMJJ (0), ASON (0), DJFM (+1), AMJJ (+1), ASON (+1).

year was expressed as normalized, i.e., deviation from the mean, divided by the standard deviation. These normalized deviations were categorised as n (normal) if these were within ±0.5s; + and - if within 0.5 to 1.0s and -0.5 to -1.0s respectively; symbol D for deviations above 1.0s and symbol O for deviations below -1.0s. Table 1 shows the deviations for Fortaleza rainfall for successive DJF, MAM, JJA, SON, for year (0) in the beginning and year (+1) in the end, for all the events, starting from those having commencements in January. The asterisk (*) indicates the season when El Niño commenced. The main rainy season for Fortaleza is MAM (0).The following may be noted in Table 1.

(i) For the first event of Jan. 1943 (* in the DJF column of Year (0)), the main season MAM (0) rainfall anomalies were slightly negative, i.e., droughts occurred, as expected; but for the event of January 1948, MAM (0) was normal. Thus, for these two El Niños starting in January, one resulted in droughts at Fortaleza main rainy season MAM but the other did not. On the other hand, the pre-rainy season DJF had deficit rains in both these events.

Table 1 - Normalized rainfall anomalies at Fortaleza during (0) and one year after (+1) each El Niño event. The symbol n means normal rainfall (within ±0.5σ), + and - mean within +0.5 to +1.0σ and -0.5 to -1.0σ respectively, Δ means above 1.0σ and O means below -1.0σ. The * marks the commencement of the event.

Event Year	DJF (0)	MAM (0)	JJA (0)	SON (0)	DJF (+1)	MAM (+1)	JJA (+1)	SON (+1)
Jan. 1943	O*	-	-	n	-	n	O	O
Jan. 1948	- *	n	n	-	-	Δ	n	-
Feb. 1949	- *	Δ	n	-	-	n	O	-
Feb. 1957-58	- *	n	-	n *	O	O	n	O
Feb. 1965-66	- *	+	Δ	- *	O	n	+	n
Feb. 1972-73	- *	O	Δ	O*	Δ	Δ	Δ	+
Feb. 1976	+*	n	-	n	n	n	Δ	+
Feb. 1993	- *	O	n	-	n	Δ	Δ	-
Average JF	-.68	.06	.22	-.56	-.36	.13	.76	-.31
Mar. 1951	O	O*	n	+	-	+	O	-
Mar. 1953	-	n *	-	n	n	-	-	O
Mar. 1969	-	Δ *	+	n	O	n	-	n
Average JFM	-.77	-.02	.16	-.37	-.43	.09	.35	-.40
Sep. 1940-41	n	n	n	- *	-	O	-	O
Oct. 1982-83	n	O	n	+*	n	O	-	-
Nov. 1986-87	Δ	Δ	+	+*	n	O	+	-
Nov. 1991-92	n	+	-	n *	n	O	n	-
Average SON	.22	.27	-.13	.28	-.27	-1.15	-.59	.84

(ii) There are 6 events with commencements in February. The rainfalls in the main season MAM (0) were deficit only in two events (1972, 1993) and normal or above normal in the other four events. Again, the pre-rainy season DJF had mostly deficit rains.

(iii) For the 3 events starting in March (*in the MAM column of year (0)), the commencement was in the beginning of the main rainy season MAM (0); but only 1951 MAM (0) showed deficit rains, while 1953 MAM (0) had normal rains and 1969 MAM (0) had excess rains. Thus, from these 3 events, only 1 showed expected El Niño effects (droughts in the MAM season) at Fortaleza.

(iv) For the 8 events starting in Jan. Feb., the average deviations are shown in Table 1 in units of standard deviations, for DJF, MAM, JJA, SON of year (0) and year (+1). These are also shown in the top plot (a) in Fig. 4. The error bars are standard deviations. As can be seen, DJF (0) and SON (0) showed significant negative deviations of ~0.5s but MAM (0) showed normal rainfall. The conclusion would be that on the average, El Niños caused rainfall deficits in these off-season periods, but not in the main rainy season MAM. The individual DJF (0) values for the 8 events were: -1.16, -.55, -.94, -.93, -.99, -.86, +.89 and -.92. Thus, only 1976 had a positive deviation (+.89). The mean of all these values was -0.68±0.23, significantly negative.

(v) For all the 11 events commencing in Jan., Feb., Mar., the average plot shown in Fig. 4 (b) again indicates negative deviations (-0.77±0.19) for DJF (0). To our knowledge, this important result (significant deficit rainfall in the pre-rainy season months DJF) is not reported in earlier literature.

(iv) For the 4 events commencing in Sep., Oct., Nov. (all double events, i.e., continuing in the next year), the average plot shown in Fig. 4 (c) shows only normal rainfall in year 0 as expected (the events occurred after the rainy season); but significant large negative deviations (-1.15±0.11) occurred for MAM (+1), indicating that in these late and/or double events, the main rainy season of the next year will show droughts. This happened for the 1957-58 event also, though 1957 was not a late event but overflowed in 1958. It did not happen in 1965-66 and 1972-73, because the second year El Niños (1966 and 1973) were very short-lived (present in January but almost disappearing in February). Hence, there is an indication that in double events, the second years will probably show droughts in the main rainy season of Fortaleza, unless the El Niño disappears quickly in the very early part of the second year.

C. Rainfall in Northeast Brazil

Individual stations can have rainfalls affected by local conditions also. Fortaleza may not necessarily represent the whole of Northeast Brazil. Hence, a similar analysis was carried out for the rainfall series for the groups of selected stations in Northeast Brazil obtained by Hastenrath (1990, and further private communication, HT series, Mar.-Sept. Rainfall, average of 27 stations in Northeast Brazil, as shown by crosses in Fig. 1) and by Rao et al. (1993, R series, Apr.-July rainfall, average of 63 stations in eastern Northeast Brazil, as shown by dots in Fig. 1). Table 2 shows the rainfall deviations, as symbols n, -, +, O, D. For double events, the second year is considered as having commencement in January.

In Table 2, the values at Fortaleza are, in general, similar to those of the HT (Hastenrath, 1990) series and, many of these do not show droughts. Among those which do show droughts (- or O), many are second year events (El Niño starting in one year and still strong in the January of the next year). The values R in eastern northeast are often different from those of HT or Fortaleza, indicating that the eastern part of northeast does not have similar variations nor similar ENSO relationships as the rest of northeast.

The numbers at the bottom of Table 2 indicate that in the Fortaleza and HT series, almost 1/3rd of the events were normal, 1/3rd had positive deviations and only a slightly larger number had negative deviations (droughts). In case of R, almost half were normal and there were almost equal numbers of positive and negative deviations. Thus, the overall relationship of El Niños with droughts in the main rainy season of NE Brazil was poor, even for El Niño events that occurred in Jan. Feb.-Mar. (just before the main rainy season) and were suitable for causing droughts. In contrast, there were significant rainfall deficits in the pre-rainy season period DJF (0) shown in Table 1 and Fig. 4, top plots.

In Table 2, from the 9 January events, 7 showed rainfall deficits in the main rainy season (MAM) of Fortaleza. But six of these (1941, 1958, 1973, 1983, 1987, 1992) were second years of double events. Thus, a tendency for second year events to show rainfall deficits in the main rainy season at Fortaleza is indicated.

D. Rainfall in São Paulo

Fig. 3 shows the climatology of São Paulo (region Água Funda) rainfall. Major rainfall is during December, January, February, March (local summer). Hence series were made for DJFM, AMJJ, ASON months and normalized deviations calculated. The relationship with El Niño events is shown in Table 3.

In Table 3, the following may be noted:

(i) For the 11El Niños commencing during Jan., Feb., Mar., the DJFM (main rainy season) rainfall deviations were normal (n) for 6 events, negative (- and O) for 4 events, and large excess (D) for 1 event. The following

Table 2 - Normalized rainfall deviations for the main rainy season of year (0) of El Niño event. For the south Brazil locations, annual rainfall is used and the * indicate El Niño events remaining strong in the end of year (0), which is the main rainy season in south Brazil. O means large rain deficits, - means small rain deficits, n means normal rains, + means small rain excesses and D means large rain excesses.

	Fortaleza MAM(0)	HT (NE) Mar-Sep.(0)	R (ENE) Apr-Jul.(0)	S. Paulo DJFM(-1,0)	S.Paulo DJFM(0,+1)	Porto Alegre Annual	Bage Annual	N.Palm Annual
41	O	-	n	O	n	Δ *	Δ	
43	-	-	-	-	-	O	O	O
48	N	n	+	n	n	-		n
58	O	O	-	O	+	n	N	n
56	N	-	Δ	+	Δ	+		+
73	Δ	+	n	-	n	n	+	n
83	O	O	O	Δ	-	Δ (?)	Δ	Δ
37	O	n		n	+			Δ
92	O	-		n	n			+
49	Δ	+	n	n	Δ	-		-
57	N	+	n	n	O	n *	-	-
65	+	Δ	n	Δ	+	+ *	+	n
72	O	n	n	-	-	Δ *	+	+
76	N	n	-	n	-	Δ *	N	Δ
93	O	O		n	n			n
51	O	-	+	n	+	- *		-
53	N	-	n	O	O	n	-	-
69	Δ	n	+	O	n	O	-	-
40	N	Δ	+	n	O	Δ *	Δ	
32	O	n	n	n	Δ	Δ *	+	+
86	Δ	Δ		+	n			Δ
91	+	n		Δ	n			O
:	6	6	5	5	7	8	7	8
e	10	9	4	7	7	5	4	7
	6	7	8	10	8	4	2	5

AMJJ (local winter) rains were normal in 6 events, negative in 3 events, and positive in 2 events. The following ASON (local spring) rains were normal for 2 events, negative for 3 events, and positive for 6 events. For ASON, the 8 values for events in January and February were: +.76, -.67, -1.38, +3.18,+.46, +1.02, +2.06, +.57, yielding an average value (+0.75±0.35), barely significant (Fig. 4d). When values for March were added (-.82, -.49, 1.48), an insignificant average (+0.56 ± 0.50) was obtained, shown in Fig. 4(e).

(ii) For the 4 El Niños commencing in Sep.-Nov., the months DJFM (0) had 2 n and 2 excesses, AMJJ (0) had 1 n, 1 negative and 2 positive (mixed results). The ASON (0) months themselves were mostly normal (3n, 1 negative); but the following summer DJFM (+1) had 2 n, 1 positive, 1 negative. The most striking effect was in the following autumn AMJJ (+1) when excess rains (D) occurred in 1983 and 1987. In Fig. 4 (f), the average value for AMJJ (+1) is (+1.15±1.10). The error is large, because the 4 individual values are widely different viz., -.45, +3.83, +2.09, -.85. It should be remembered that the São Paulo data refer only to one location Água Funda in the large city of São Paulo. Often, other parts may show slightly different monthly rainfalls. Also, the topography of the region around the city and down to the coast (about 50 km away) is highly variable. Xavier et al. (1995) mention that, for several stations in and around São Paulo and around the eastern slopes facing the

Table 3 - Normalized rainfall anomalies at São Paulo during (0) and one year after (+1), each El Niño event. The symbol n means normal rainfall (within ±0.5s), + and - mean within +0.5 to +1.0s and -0.5 to -1.0s respectively, D means above 1.0s and O means below -1.0s. The * marks the commencement of the event.

Event (0)	DJFM (0)	AMJJ (0)	ASON (0)	DJFM (+1)	AMJJ (+1)	ASON (+1)
Jan. 1943	- *	O	+	-	O	-
Jan. 1948	n *	n	-	N	n	O
Feb. 1949	n *	n	O	Δ	n	n
Feb. 1957-58	n *	n	Δ	O	Δ	n
Feb. 1965-66	Δ *	+	n	+	n	n
Feb. 1972-73	- *	-	Δ	-	n	n
Feb. 1976	n *	Δ	Δ	-	n	n
Feb. 1993	n *	n	+	N	-	O
Average JF	0	.03	.75	-.14	-.24	-.43
Mar. 1951	n *	-	-	+	-	-
Mar. 1953	O*	n	n	O	n	O
Mar. 1969	O*	n	Δ	N	n	n
Average JFM	-.25	-.06	.56	-.09	-.28	-.51
Sep. 1940-41	n	O	- *	O	n	Δ
Oct. 1982-83	n	Δ	n *	Δ	Δ	Δ
Nov. 1986-87	+	n	n *	N	Δ	O
Nov. 1991-92	Δ	+	n *	N	-	Δ
Average SON	.88	.20	-.35	.09	1.15	.73

Atlantic, rainfall extremes occurred in April, May and June of ENSO events and May 1983 and May 1987 showed exceptional extremes. The reference is obviously to the values +3.83 and +2.09 mentioned above. But in 1941 and 1992, the values were reverse (-.45 and -.85). For 1958, the value was +0.27 (normal). These authors selected only 1958, 1983 and 1987 as El Niño episodes and showed their marked influence on the May rainfall values around São Paulo, with decreasing values from the northwest and north to the southeast and south. However, as seen in Table 3, in several other El Niño episodes, neither the AMJJ (0) nor AMJJ (+1) show any rainfall extremes. Incidentally, the 3 events selected by them (1958, 1983, 1987) were all second year events. Thus, our results, based on many more El Niño events, are slightly different from those of Xavier et al (1995). However, our results are not necessarily more relevant than those of Xavier et al (1995); because we have used data of only one city, São Paulo.

(iii) Overall, the El Niño effects on São Paulo rainfall seem to be erratic. In Table 2, the bottom part shows a large number of normal rainfalls, and an almost equal number of positive and negative deviations. Thus, the relationship with El Niños is very poor. The slight excess in ASON months is not very meaningful.

E. Rainfall in South Brazil

For south of Brazil, only annual values were available to us up to 1985. Table 2 (last columns) show the rainfall categories. From data for 17 events, Porto Alegre (30o01'S, 51o13'W) had 8 positive deviations, 5 negative deviations and 4 normal deviations. Thus, only a slight bias for excess rains is indicated; but in almost half the cases, the rainfall was normal or deficit. From the 17 events, only 7 had rainfalls opposite in NE Brazil and Porto Alegre (5 negative in NE, positive at Porto Alegre; 2 positive in NE, negative at Porto Alegre). In 2 events each, NE and Porto Alegre were both positive or both negative. In 6 events, either NE or Porto Alegre had normal rains. Roughly similar results were seen for Bage (31o20'S, 54o06'W) and Nova Palmira (29o19'S, 51o11'W) in south Brazil. Thus, the popular belief that NE Brazil and south Brazil rainfalls are opposite to each other (droughts in one, excess rains at the other, or vice versa) does not seem to be invariably true.

Regarding the occurrences of excess rains in south Brazil associated with El Niños, Table 2 shows a very interesting result. The major rainy season in south Brazil is August-December. If the El Niño started in Jan., Feb., Mar., it is important to know whether it persisted strong in the later part of the year. In the column for Port Alegre in Table 2, the * indicates the El Niño events which were strong during Aug.-Dec. also (as seen in Fig. 2a). In 1940, 1941, 1965, 1972, 1976, 1982, the El Niños were strong even in the later part of the year and Porto Alegre rainfalls were D, D, +, D, D, D i.e., mild or severe excesses, completely as per expectation. In 1957, El Niño was strong up to August, faltered during Sept.-Nov. and strengthened thereafter, overflowing into 1958; the Porto Alegre rainfall was normal (n). In 1951 and 1983, the El Niños were fading out after August and Porto Alegre rainfalls were - and D. In other El Niño years, 1943, 1948, 1949, 1953, 1958, 1966, 1969, 1973, the El Niños started in the early part of the year, but faded by August and the Porto Alegre rainfalls were O, -, -, n, n, +, O, n, i.e., mostly normal (n) or negative, except in 1966 when the rainfall was +. Thus, strong El Niños commencing or continuing in the later part of the year (roughly coinciding with the main rainfall season) seems to be an important criterion for excess rainfall in south Brazil. These results refer to Porto Alegre; but almost similar results were seen for Bage and Nova Palmira, locations few hundred km away from each other and hence, representative of a large part of south Brazil.

4. RAINFALL PREDICTIONS FOR 1997-1998

During 1997, a strong El Niño developed. The forecasts for Northeast Brazil rainfall issued in January 1997, based on variations of Atlantic and Pacific parameters, were mostly of moderately dry conditions (Colman et al., 1997; Harrison et al., 1997; Graham, 1997; Greischar and Hastenrath, 1997). The observed rainfall in Northeast Brazil in Mar.-May 1997 was a few percent below normal in some parts and normal in others, thus, basically conforming to the above predictions. In the present analysis, the relationship of first year El Niños with rainfalls in Northeast Brazil is shown to be not very good. Thus, normal rainfall in 1997, in spite of a strong El Niño starting in early 1997, is not a novelty. However, the El Niño was strong even in the first half of 1998. As such, 1997-98 is a double event. In previous double events, most of the second years showed droughts in Northeast Brazil. Hence, a drought in MAM months was expected in Northeast Brazil in 1998, and came true.

For São Paulo, according to Xavier et al. (1995), the AMJJ rainfalls should have been positive extremes. The observed values were +0.79 for DJFM (1997) and +0.03 for AMJJ (1997). Neither of these are extremes. Since the El Niño continued strong in the first half of 1998, the AMJJ values of 1998 could have been positive extremes as in 1983 and 1987, normal as in 1958, 1966, 1973, or negative as in 1943, 1951, 1972, in short, very uncertain. Thus, the observed values in 1997-98 seem to be in disagreement with the expectations mentioned in Xavier et al (1995). However, this comparison should be considered with great reservation, as rainfall data for only São Paulo city is considered by us.

For Porto Alegre and other parts of south Brazil, the main rainfalls are in the latter half of the calendar year. The El Niño was strong throughout 1997 and there were excess rains in south Brazil, as expected. The El Niño continued strong in the first few months of 1998 but started fizzling out and there was no El Niño in the latter half of 1998. (In fact, a La Niña seems to have developed). Hence, by the previous records presented in the present communication, the south Brazil rainfall in the latter half of 1998 should have been normal. This needs confirmation.

5. CONCLUSIONS AND DISCUSSION

(A) The rainfalls at Fortaleza, Ceará and the average for selected groups of stations in NE Brazil were examined for relationship with El Niño events commencing in different months. Major rainfall occurs in this region in MAM (March, April, May). The following was noted:

(i) For events commencing in Jan., Feb., Mar., of year (0), the relationship with main season MAM (0) rainfall was very poor; but DJF (0) (pre-season rainfall) and SON (0) (post-season rainfall) showed deficit rains. The implication of this finding needs further exploration.
(ii) There were no events commencing in April, May,

June, July, August. For events commencing in Sept., Oct. Nov., and continuing in the next year, the main rains in MAM of next year were largely deficit, as expected.
(iii) In double events, the second year already had a strong El Niño in January (by definition), which lasted for several months more. In almost all these (second) years, Northeast Brazil had droughts. Only exceptions were 1966 and 1973 when these second year events lasted for only a month or two.

(B) The rainfalls in São Paulo (southeast) and Port Alegre (south) Brazil showed the following:

(i) In São Paulo, the main rainy season is December, January, February, March (DJFM). For El Niño events commencing in Jan., Feb., Mar., the ASON (0) (pre-season rainfall) was slightly (but insignificantly) excess. The main season DJFM (0) rainfall was normal. For El Niño events commencing in Sept., Oct., Nov., the DJFM rainfall several months earlier and the AMJJ rainfall several months later were slightly excess. However, these results were of only borderline significance.
(ii) For Porto Alegre and other parts of south Brazil, the rainfalls are believed to be opposite to those of NE Brazil. This opposite relationship was often not noticed, mainly because some El Niños commencing in the early part of the year and lasting for a few months only affect NE Brazil rainfall (giving droughts) but not south Brazil, while El Niños commencing or continuing in the later part of the year give excess rains in south Brazil only but have no effect on NE Brazil.

Overall, the relationship between El Niño occurrences and extreme rainfalls in NE Brazil and São Paulo is loose. Our hope that the commencement months could explain the non-effectiveness of some El Niños was not fulfilled. But, in south Brazil, late El Niños did result in excess rains obviously, other factors unrelated to ENSO were playing important roles. The role of other factors unrelated to ENSO is already known since long. For NE Brazil, a considerable influence of tropical Atlantic SST was reported long ago (Markham and McLain, 1977). Other factors considered are, 700 mb circulation pattern over the North Atlantic (Namias, 1977), meridional displacement and strength of the Intertropical Convergence Zone (ITCZ) (Hastenrath and Heller, 1977), Atlantic Trade Winds (Chung, 1982), rainfall systems associated with tropical disturbances moving westward from the Atlantic towards Northeast Brazil (Ramos, 1975; Yamazaki and Rao, 1977; Rao et al., 1993), and southern hemisphere cold fronts or their remains moving northward along the Northeast coast of Brazil (Kousky and 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 and Heller, 1977; Moura and Shukla, 1981). According to Hastenrath (1990), droughts in Northeast Brazil can be due 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. Prediction schemes based on these ideas have been formulated by Hastenrath et al. (1984), Hastenrath (1990), Hastenrath and Greischar (1993), Hastenrath and Druyan (1993) (see also Ward and Folland, 1991). Earlier, Servain and Siva (1987) had investigated the relationship between tropical Atlantic SST, wind stress and regional precipitation indices and shown that for the seasonal time scale, the northward displacement of the ITCZ was accompanied by the strengthening of the southeast trades and/or relaxation of the northeast trades which is correlated with a decrease in NE Brazil rainfall. Recently, Wainer and Soares (1997) showed that for NNE Brazil, this was true on an interdecadal time scale also. Forecast methods based on Atlantic SST conditions initiated by Ward and Folland (1991) are being used copiously now and forecasts are made by January for the coming rainy season MAM of NE Brazil. These forecasts seem to be fairly accurate (Colman et al., 1997; Harrison et al., 1997; Graham, 1997; Greischar and Hastenrath, 1997; Cavalcanti et al., 1998a,b). As such, the great importance given to El Niño phenomenon only in the local mass media (press, radio, and television) seems to be unwarranted and could lead to disappointments and frustrations when predictions go haywire.

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7. REFERENCES

ANGELL, J. K. Comparison of variations in atmospheric quantities with sea surface temperature variations in the equatorial eastern Pacific. **Mon. Wea. Rev.** v.109, 230-43, 1981

CAVALCANTI, I. F. A., et al. **Climate prediction of precipitation in Brazil for the nordeste rainy season.** Washington: CPC, 1998. p.24-7. (Experimental Long-lead Forecast Bulletin, v.7, n.1).

CAVALCANTI, I. F. A., et al. **Climate Prediction of precipitation over South America for DJF 1998/99 and MAM 1999. Washington: CPC,** 1998b. P. 24-7. (Experimental Long-lead Forecast Bulletin, v.7, n.4).

CHUNG, J.C. Correlations between the tropical Atlantic trade winds and precipitation in NE Brazil. **J. Climatol**. v.2, p.35-46, 1982.

COLMAN, A., **Multiple regression, discriminant analysis predictions of mar-apr-may 1997 rainfall in northeast Brazil.** Washington D. C.: CPC**, 1997.** (Experimental Long-Lead Forecast , Bulletin, v.6, n.1).

DESER, C., WALLACE, J. M. El Niño events and their relation to the southern oscillation: 1925-1986. **J. Geophys. Res.** 92, 14189-14196, 1987.

GRAHAM, N. 1997. **Prediction of precipitation in northeast Brazil for boreal spring using an atmospheric GCM with persisted SST anomalies.** Washington D. C.: CPC, 1997. (Experimental Long-Lead Forecast, Bulletin, v.6, n.1).

GREISCHAR, L., HASTENRATH, S. **Multiple regression and discriminant analysis to predict mar-apr-may-jun 1997 rainfall in northeast Brazil.** Washington D.C.: CPC, 1997. (Experimental Long-Lead Forecast, Bulletin, v.6, n.1).

HARRISON, M., et al. **A dynamical one-month lead seasonal rainfall prediction for March to May 1997 for the north-eastern area of South America**. Washington D.C.: CPC, 1997. (Experimental Long-Lead Forecast Bulletin, v. 6, n.1) 1997.

HASTENRATH, S., Prediction of northeast Brazil rainfall anomalies. **J. Clim** v.3, p.893-904, 1990.

HASTENRATH, S., DRUYAN, L. Circulation anomaly mechanisms in the tropical Atlantic sector during the northeast Brazil rainy season: results from the GISS General Circulation Model. **J. Geophys. Res**., v.98, p.14917-23, 1993.

HASTENRATH, S., GREISCHAR, L. Circulation mechanisms related to northeast Brazil rainfall anomalies. **J. Geophys. Res**. v.98, p.5093-5102, 1993.

HASTENRATH, S., HELLER, L. Dynamics of climate Hazards in northeast Brazil. **Q. J. R. Meteorol. Soc.** v.103, p.77-92, 1977.

HASTENRATH, S., WU M-C, CHU, P-S. Towards the monitoring and prediction of northeast Brazil droughts. **Q. J. R. Meteorol. Soc.** v.110, p.411-25, 1984.

HUSHKE R. E. **Glossary of meteorology.** Boston: American Meteorological Society, 1959.

KANE, R. P. El Niño and La Nina events and rainfall in NE and south Brazil. **Rev. Bras. Geof.**, v.10, n.2, p.49-59, 1992.

KANE, R. P. Prediction of droughts in north-east Brazil: Role of ENSO and use of periodicities. **Int. J. Climatol.** v.17, p.655-65, 1997.

KOUSKY, V. E. Frontal influences on northest Brazil. **Mon. Wea. Rev.**, v.107, p.1140-53, 1979.

KOUSKY, V. E., CHU, P. S. Fluctuations in annual rainfall for Northeast Brazil. **J. Meteorol. Soc. Jpn.** v.56, p.457-65, 1978.

MARKHAM, C. G. MCLAIN, D. Sea surface temperature related to rain in Ceará, north-eastern Brazil. **Nature**, v.265, p.320-3, 1977.

MOURA, A. D., SHUKLA, J., On the dynamics of droughts in northeast Brazil: observations, theory and numerical experiments with a General Circulation model. **J. Atmos. Sci.**, v.38, p.2653-75, 1981.

NAMIAS, J. Influences of northern hemisphere general circulation on drought in Northeast Brazil. **Tellus**, v.24, p.336-42, 1977.

PARKER, E. E. Documentation of a southern oscillation index. **Meteorol. Mag.** v.112, p.184-88, 1983.

QUINN, W. H. et al. Historical trends and statistics of the Southern Oscillation, El Niño and Indonesian droughts. **Fish. Bull.** v.76, p.663-78, 1978.

QUINN, W. H., NEAL, V. T. ANTUNES de MAYOLO, S. E. El Niño occurrences over the past four and a half centuries. **J. Geophys. Res.** v.92, p.14449-61, 1987.

QUIROZ, R. S. The climate of the "El Niño" winter of 1982-83 - A season of extraordinary climate anomalies. **Mon. Wea. Rev.** v.111, p.1685-1706, 1983.

RAMOS, R. P. L. Precipitation characteristics in the northeast Brazil dry region. **J. Geophys. Res.** v.80, p.1665-78, 1975.

RAO, V. B., LIMA, M. C., FRANCHITO, S. H. Seasonal and interannual variations of rainfall over eastern Northeast Brazil. **J. Clim.** v.6, p.1754-63, 1993.

SERVAIN, J. SEVA, M. On relationship between tropical Atlantic sea surface temperature, wind stress and regional precipitation indices: 1964-1984. **Ocean Air Interac.** v.1, p.183-90, 1987.

TRENBERTH, K. E. The definition of El Niño. **Bull. Am. Meteorol. Soc.,** v.78, p.2771-7, 1997.

WAINER, I., SOARES, J. North northeast Brazil rainfall and its decadal-scale relationship to wind stress and sae surface temperature. **Geophys. Res. Lett.,** v.24, p.277-80, 1997.

WARD, M. N., FOLLAND, C. K. Prediction of seasonal rainfall in the north nordeste of Brazil using eigenvectors of sea-surface temperature. **Int. J. Clim.** v.11, p.711-43, 1991.

WRIGHT, P. B. **The southern oscillation patterns and mechanisms of the teleconnections and the persistence Rep. HIG 77-13.** Hawaii: p.107. Hawaii Institute of Geophysics, 1977.

WRIGHT, P. B. Relationship between indices of the southern oscillation. **Mon. Wea. Rev.** v.112, p.1913-19, 1984.

XAVIER T. Ma. B., SILVA DIAS M. A. F., XAVIER A. F. S. Impact of ENSO episodes on the autumn rainfall patterns near São Paulo, Brazil. **Int. J. Climatol.** v.15, p.571-84, 1995.

YAMAZAKI, Y. RAO, V. B. Tropical cloudiness over the south Atlantic Ocean. **J. Meteorol. Soc. Jpn.** v.55, p.205-7, 1977.