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AN APPRAISAL OF THE DURATION OF THE RECENT DROUGHT IN NORTHEAST BRAZIL

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The rainfall patterns for 1981 and 1982 for 36 stations in the Brazilian Northeast region were studied. In March 1981, there was widespread rainfall and hence the rainy season (March, April, May) rainfall was normal or above normal, specially at locations of low average rainfall (arid regions). However, in the other months of 1981, rainfall was far below normal. Hence the yearly total rainfall for 1981 was below normal. For 1979, 1980, 1981, 1982 and 1983, the yearly average rainfall for the 36 stations was —10%, —15%, —17%, —18% and —44%, respectively, indicating that this whole interval of 5 years was a *deficit* rainfall interval, the worst year being, of course, 1983. Whether this can be considered a 5 year period of *prolonged drought* depends upon what below-normal level characterizes a drought.

Foram estudados os padrões de precipitação em 36 estações no Nordeste brasileiro para os anos de 1981 e 1982. Em março de 1981 as chuvas foram gerais em toda a região e portanto a estação chuvosa (março, abril, maio) foi normal, ou acima do normal, especialmente em locais de baixa precipitação média (regiões áridas). Contudo, em outros meses de 1981, a precipitação esteve bem abaixo do normal. Portanto o índice pluviométrico anual de 1981 foi abaixo do normal. Para 1979, 1980, 1981, 1982 e 1983, as médias anuais de precipitação para as 36 estações, ficaram —10%, —15%, —17%, —18% e —44% abaixo da média, respectivamente, indicando que todo esse intervalo de 5 anos foi um período de *déficit* de precipitação, tendo sido 1983, certamente, o pior. Esse período de 5 anos será considerado de *seca prolongada,* dependendo do nível abaixo do normal que caracteriza uma seca.

INTRODUCTION

Markham (1974) analysed the rainfall series for Fortaleza (Ceará, Northeast Brazil) and detected two significant periodicities of 13 and 26 years. Girardi & Teixeira (1978) used these periodicities and made a forecast that 1979-1985 would be an interval of prolonged drought. Using the more sophisticated method of Maximum Entropy Spectral Analysis (MESA), Kane & Trivedi (1984) examined the Fortaleza series for 1849-1976 and arrived at a similar conclusion.

There is no doubt that a drought did occur in Northeast Brazil in the recent past, the worst year being 1983. However, there seems to be some difference of opinion about the duration of this drought. Girardi and Teixeira predicted a *continuous* drought for 1979-1985 and newspaper and television reports have always referred to the last few years as "five years of prolonged drought". On the other hand, some workers (Nobre et al., 1984; Rao & De Britto, 1984; De Britto 1984) have claimed that 1981 and 1982 were not years of drought. Their claim is based upon an analysis of the rainfall data for 20 stations, for the period 1964-1983. In Fig. 1(a), we reproduce the diagram frm Rao & De Britto (1984), which shows that the rainfall for 1981 was above normal and the rainfall for 1982 was slightly below normal.

In the present communication, we examine this evidence critically.

ANALYSIS

A critical examination of the data used for Fig. 1(a) reveals the following:

(i) This diagram refers to the average rainfall for the months of March, April and May only. The authors chose these months as these constitute the "rainy season", with more than 50% of the yearly rainfall occurring in these months. This assumption is not correct for all the 20 stations chosen by these authors (see Table 1). For Ceará Mirim (RN), Campina Grande (PB) and Surubim (PE) there is considerable rainfall in June-July and for Remanso (BA), in December. However, for the other 16 stations the assumption is correct and the results should have been fairly representative of the yearly rainfall, but for a curious occurrence as follows.

Table 1 — Deviations from Mean by the three methods A, B and C in 1981 and 1982 for various stations Stations 1-20 are the same used by Rao and Britto (1984). Values with an asterisk (*) are approximate.

STATIONS	Geographic			Average Rainfall (mm) (1968-83)		Standard Deviation of Rainfall (mm)		For (Mar. Apr. May) 1981		
	Lat (South)	Long (West)	Maximum Rainfall Is In	Mar Apr May	Whole Year	Mar Apr May	Whole Year	A Deviation From Mean (mm)	B Percentage Deviation From Mean	C Deviation Expressed In Units of Std. Dev.
01 — Barra da Corda (MA)	5°31′	45°15′	Mar. Apr.	407	1090	188	212	−32	−8	−0.17
02 — Floriano (PI)	6°46′	43°01′	Mar. Apr.	350	1056	212	341	+98	+28	+0.46
03 — Picos (PI)	7°05′	41°28′	Mar. Apr.	285	725	132	192	+161	+56	+1.22
04 — Terezina (PI)	5°04′	42°49′	Mar. Apr.	559	1210	180	250	−174	−31	−0.97
05 — Crateus (CE)	5°11′	40°40′	Mar. Apr.	465	737	265	307	−187	−40	−0.71
06 — Fortaleza (CE)	3°42′	38°31′	Mar. Apr.	833	1536	305	490	−39	−5	−0.13
07 — Guaramiranga (CE)	4°15′	38°57′	Mar. Apr.	882	1645	360	606	−151	−17	−0.42
08 — Iguatu (CE)	6°22′	39°18′	Mar. Apr.	431	895	178	303	−130	−30	−0.73
09 — Quixeramobim (CE)	5°12′	39°18′	Mar. Apr.	439	774	144	256	−63	−14	−0.44
10 — Sobral (CE)	3°42′	40°21′	Mar. Apr.	519	813	193	338	−138	−27	−0.72
11 — Tauá (CE)	6°01′	40°25′	Mar. Apr.	292	521	186	219	+171	+59	+0.92
12 — Ceará Mirim (RN)	5°38′	35°26′	Apr. Jun.	507	1154	189	325	−120	−24	−0.63
13 — Cruzeta (RN)	6°25′	36°47′	Mar. Apr.	421	658	186	230	−125	−30	−0.67
14 — Campina Grande (PB)	7°13′	35°52′	May. Jun.	360	764	103	155	+14*	+4*	+0.14*
15 — S. Gonçalo (PB)	6°50′	38°19′	Mar. Apr.	461	949	175	284	+85	+18	+0.49
16 — Pesqueira (PE)	8°22′	36°42′	Apr. May.	334	702	138	239	+54	+18	+0.39
17 — Petrolina (PE)	9°23′	40°30′	Feb. Mar.	202	528	136	110	+216	+107	+1.59
18 — Surubim (PE)	7°50′	35°45′	May. Jun.	282	660	117	186	−28*	−10*	−0.24*
19 — Triunfo (PE)	7°50′	38°07′	Mar. Apr.	531	1200	217	356	−11	−2	−0.05
20 — Remanso (BA)	9°41′	42°04′	Dec. Mar.	193	561	113	141	+217	+112	+1.92
(20 stations) Sum				8753	18178			−182	+162	+1.25
Average (mm)				438	909			−9		
Percent								−2	+8	+0.06
21 — Barbalha (CE)	7°19′	39°18′	Mar. Apr.	460	1050	186	312	−83	−18	−0.45
22 — Campos Sales (CE)	7°04′	40°23′	Mar. Apr.	279	580	146	188	+35	+13	+0.24
23 — Morada Nova (CE)	5°06′	38°23′	Mar. Apr.	453	770	166	284	−143	−32	−0.86
24 — Florània (RN)	6°07′	36°49′	Mar. Apr.	448	714	213	276	−132	−29	−0.62
25 — João Pessoa (PB)	7°08′	34°53′	May. Jun.	729	1764	227	447	−55	−8	−0.24
26 — Patos (PB)	7°01′	37°17′	Mar. Apr.	415	726	146	245	+40	+10	+0.27
27 — Recife (PE)	8°03′	34°55′	May. Jun.	827	2234	197	341	−343	−41	−1.74
28 — Garanhuns (PE)	8°53′	36°29′	Jun. Jul.	311	797	126	215	+86	+28	+0.68
29 — Coruripe (AL)	10°07′	36°10′	May. Jun.	586	1479	204	453	−182	−31	−0.89
30 — Maceió (AL)	9°39′	35°43′	May. Jun.	732	1776	361	525	−292	−40	−0.81
31 — Água Branca (AL)	9°17′	37°56′	May. Jun.	365	982	166	301	+178	+49	+1.07
32 — Palmeira dos I. (AL)	9°24′	36°39′	May. Jun.	342	898	119	269	+66	+19	+0.55
33 — Pão de Açúcar (AL)	9°44′	37°26′	May. Jun.	236	582	88	203	+17	+7	+0.19
34 — Aracaju (SE)	10°54′	37°03′	May. Jun.	567	1347	203	288	−92	−16	−0.45
35 — Itabaianhinha (SE)	11°16′	37°47′	May. Jul.	245	786	73	185	+55*	+22*	+0.75*
36 — Salvador (BA)	13°01′	38°31′	Apr. May.	736	1995	248	497	−90	−12	−0.36
(16 stations) Sum				7731	18480			−935	−79	−2.67
Average (mm)				483	1155			−58		
Percent								−12	−5	−0.17
(36 Stations) Sum				16484	36658			−117	+83	−1.42
Average (mm)				458	1018			−31		
Percent				458	1018			−7	+2	−0.04

Table 1 — Cont.

For Whole Year 1981			For (Mar. Apr. May) 1982			For Whole Year 1982		
A Deviation From Mean (mm)	B Percentage Deviation From Mean	C Deviation Expresso In Units of Std. Dev.	A Deviation From Mean (mm)	B Percentage Deviation From Mean	C Deviation Expressed In Units of Std. Dev.	A Deviation From Mean (mm)	B Percentage Deviation From Mean	C Deviation Expressed In Units of Std. Dev.
−110	−10	−0.52	−35	−9	−0.19	−149	−14	−0.70
−179	−17	−0.52	−132	−38	−0.62	−329	−31	−0.96
+19	+3	+0.10	+55	+19	+0.42	−118	−16	−0.61
−302	−25	−1.21	+111	+20	+0.62	+5	0	+0.02
−281	−38	−0.92	−115*	−24*	−0.43*	−157*	−21*	−0.51*
− 436	−28	−0.89	−276	−33	−0.90	−532	−35	−1.09
−442	−27	−0.73	−37	−4	−0.10	−203	−12	−0.33
−183*	−20*	−0.60*	−92	−21	−0.52	−195	−22	−0.64
−164	−21	−0.64	−22	−5	−0.15	−75	−10	−0.29
−289	−36	−0.86	−30	−6	−0.16	−46	−6	−0.14
+82	+16	+0.37	−106	−36	−0.57	−121	−23	−0.55
−236	−20	−0.73	−102	−20	−0.54	−29	−3	−0.09
−128*	−19*	−0.56*	−77*	−18*	−0.41*	−133*	−20*	−0.58*
−42*	−5*	−0.27*	−112	−31	−1.09	−64	−8	−0.41
−43	−5	).15	−147	−32	−0.84	−219	−23	−0.77
−162	−23	−0.68	+16*	+5*	+0.12*	−122*	−17*	−0.51*
+58	+11	+0.53	−22	−11	−0.16	−203	−38	−1.84
−152	−23	−0.82	−141	−50	−1.21	−136	−21	−0.73
−300	−25	−0.84	−41*	−8*	−0.19*	−370*	−31*	−1.04*
+11	+2	+0.08	−56	−29	−0.50	−284	−51	−2.01
−3279	−310	−9.86	−1361	−331	−7.42	−3480	−402	−13.78
−164			−68			−174		
−18	−16	−0.49	−16	−17	−0.37	−19	−20	−0.69
−468	−45	−1.50	−173	−38	−0.93	−509	−48	−1.63
−95	−16	−0.51	−85	−30	−0.58	−129	−22	−0.69
−250	−32	−0.88	−34	−8	−8	−0.20	−19	−0.52
−130	−18	−0.47	−6	−1	−0.03	−154	−22	−0.56
−236	−13	−0.53	−229*	−31*	−1.01	−64*	−4*	−0.14*
−166	−23	−0.68	−165*	−40*	−1.13*	−366*	−50*	−1.49*
−613	−27	−1.80	−244	−30	−1.24	−290	−13	−0.85
+30	+4	+0.14	−11*	−4*	−0.09*	−137*	−17*	−0.64*
−329	−22	−0.73	+281	+48	+1.38	−79*	−5*	−0.17*
−318	−18	−0.61	+481	+66	+1.33	+374	+21	+0.71
−82	−8	−0.27	−49	−13	−0.30	−202	−21	−0.67
−208	−23	−0.77	+66	+19	+0.55	−218*	−24*	−0.81*
−82	−14	−0.40	−82	−35	−0.93	−147*	−25*	−0.72*
−278	−21	−0.97	−109	−19	−0.54	−116	−9	−0.40
+114*	+15*	+0.62*	+87	+36	+1.19	+174	+22	+0.94
−506	−25	−1.02	+33	+4	+0.13	−193	−10	−0.39
−3617	−286	−10.38	−239	−76	−2.40	−2205	−246	−8.03
−226			−15			−138		
−20	−18	−0.65	−3	−5	−0.15	−12	−15	−0.50
−6896	−596	−20.24	−1600	−407	−9.82	−5685	−648	−21.81
−192			−44			−158		
−19	−17	−0.56	−10	−11	−0.27	−16	−18	−0.61

(ii) In March 1981, it rained heavily almost all over Northeast Brazil, contributing about 200 mm of rainfall. The authors are aware of this strange occurrence as seen from Fig. 1(b), which we have reproduced from the Masters thesis of De Britto (1984). Here, the rainfall for March, April and May are shown separately. As can be seen, the rainfall for March 1981 was very much above normal, while the rainfall for April 1981 was below normal and that for May 1981 was very much below normal. The above authors have not made any mention of rainfall during the rest of the year; but our examination showed that the rainfall in the other months of 1981 was *below* normal for many locations. The normal or above normal rainfall in March-April-May of 1981 and the below normal rainfall in the other months had different implications in different places, as follows.

(iii) For locations having low average yearly rainfalls (200-400 mm), the downpour in March 1981 was so large that it compensated for the deficit in the other months and the yearly rainfall was, therefore, normal or above normal. For locations having larger average rainfalls, the compensatory effects were lesser and, for many of these, the rainy season rainfall was normal while the yearly rainfall was below normal.

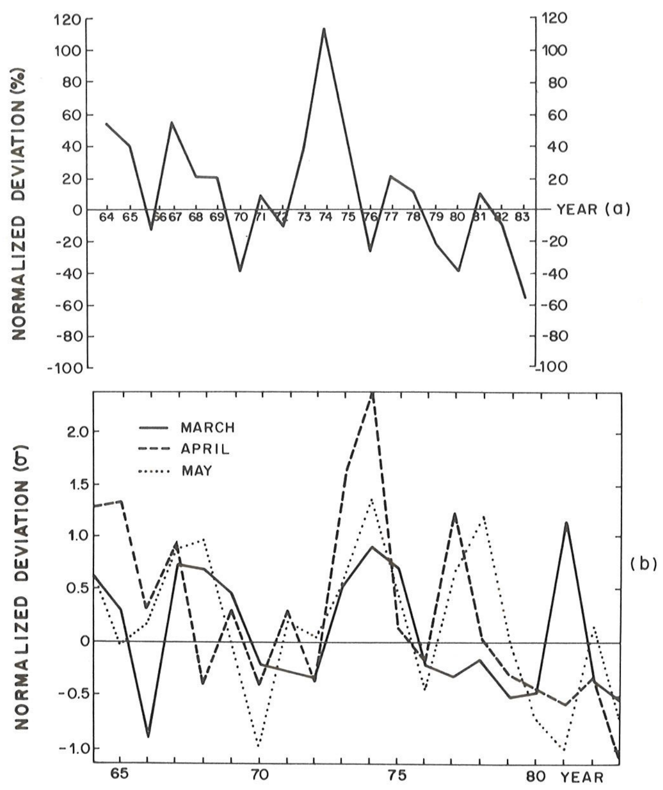

Figure 1 — Average rainfall for 20 stations in Northeast Brazil for 1964-1983 (Diagrams reproduced from Rao & De Britto, 1984 and De Britto, 1984):
(a) Average for March, April, May;
(b) Separate plots for March, April and May.

(iv) In Fig. 2, we show the plot of percentage deviations from mean for a few selected locations for 1968-1983. On the left hand side, all plots show deviations below normal for 1981 and 1982, more so for the yearly total rainfall (full lines). On the right hand side, all locations show very large *positive* deviations for the rainy season rainfall (dashed lines) for 1981, while the yearly total rainfalls (full lines) for 1981 are near or below normal. Thus, the normal or above normal values for 1981 shown by Rao & De Britto are mainly due to their use of rainy season values. It is interesting to note that only locations having low yearly average rainfalls (about 800 mm or less) show large positive percentage deviations in 1981. Since negative deviations can be at the worst – 100% (no rainfall!) while positive deviations can be several hundred percent, the large positive deviation on a single station (e.g. Petrolina, +107% for March-April-May of 1981) could neutralise small negative deviations (e.g. Quixeramobim, –14%) of several stations and give an impression of an overall positive deviation for the whole region, while in reality many may have negative deviations and only a few may have large positive deviations.

This raises an important question, viz, how should data from several locations be averaged. Usually, three methods are employed. If there are k stations (i = 1 to k), each having data for n years (j = 1 to n), the mean, deviations from mean and the standard deviation for any station i are given by:

$$\text{Mean } \bar{x}^i = (1/n) \sum_{j=1}^{n} x^i_j .$$

$$\text{Deviations from mean} = \Delta x^i_j = x^i_j - \bar{x}^i , j = 1 \text{ to } n.$$

$$\text{Standard deviation } \sigma^i = [(1/n) \sum_{j=1}^{n} (\Delta x^i_j)^2]^{1/2}.$$

(a) *Method A:* In this method, the deviations from mean for different locations are averaged directly. Thus,

$$\Delta x_j = (1/k) \sum_{i=1}^{k} \Delta x^i_j .$$

The Δx_j so obtained may then be expressed as percentage of the master mean $\bar{x}$, where

$$\bar{x} = (1/k) \sum_{i=1}^{k} \bar{x}^i .$$

Final *series* is $(\Delta x_j/\bar{x}) . 100$, (j=1 to n). It is obvious that locations having larger average rainfall (larger $\bar{x}^i$) will have a larger weight in the final series.

(b) *Method B:* In this method, the deviations from mean for each location are expressed as percentage of the mean for that location. Later the deviations for different locations are averaged. Hence, final *series* is

$$\frac{1}{k}\sum_{i=1}^{k}\left[\left(\frac{\Delta x_j^i}{\bar{x}^i}\right).100\right], \quad (j = 1 \text{ to } n).$$

This method is used by Rao and De Britto (1984) and De Britto (1984) and the final series are plotted as in Figure 1(a) and (b). In this method, locations having lower average rainfalls (small $\bar{x}^i$) have larger weights.

(c) *Method C:* In method B, locations with scarce rainfall get unduly large weight. In general, such locations have a larger percentage of year-to-year variability. For example, for Northeast Brazil, Kousky (1979) mentions that areas of large annual rainfall have low relative variability (< 20%), while arid regions have a high relative variability (>40%). Hence, undue weightage of the arid region in Method B *could be reduced* if the deviations from mean are expressed not as percentage of the series mean, but as fractions of the standard deviation. Thus, in Method C the final *series* is:

$$\frac{1}{k}\sum_{i=1}^{k}\left[\frac{\Delta x_j^i}{\sigma^i}\right], \quad j=1 \text{ to } n.$$

This method is recommended by the World Meteorological Organization (WMO) and was used by Hastenrath & Heller (1977) for locations in Northeast Brazil.

We will now examine the data for 1968-1983 for the "rainy season" rainfall as also for the yearly total rainfall for several stations. Table 1 gives the details of the stations.

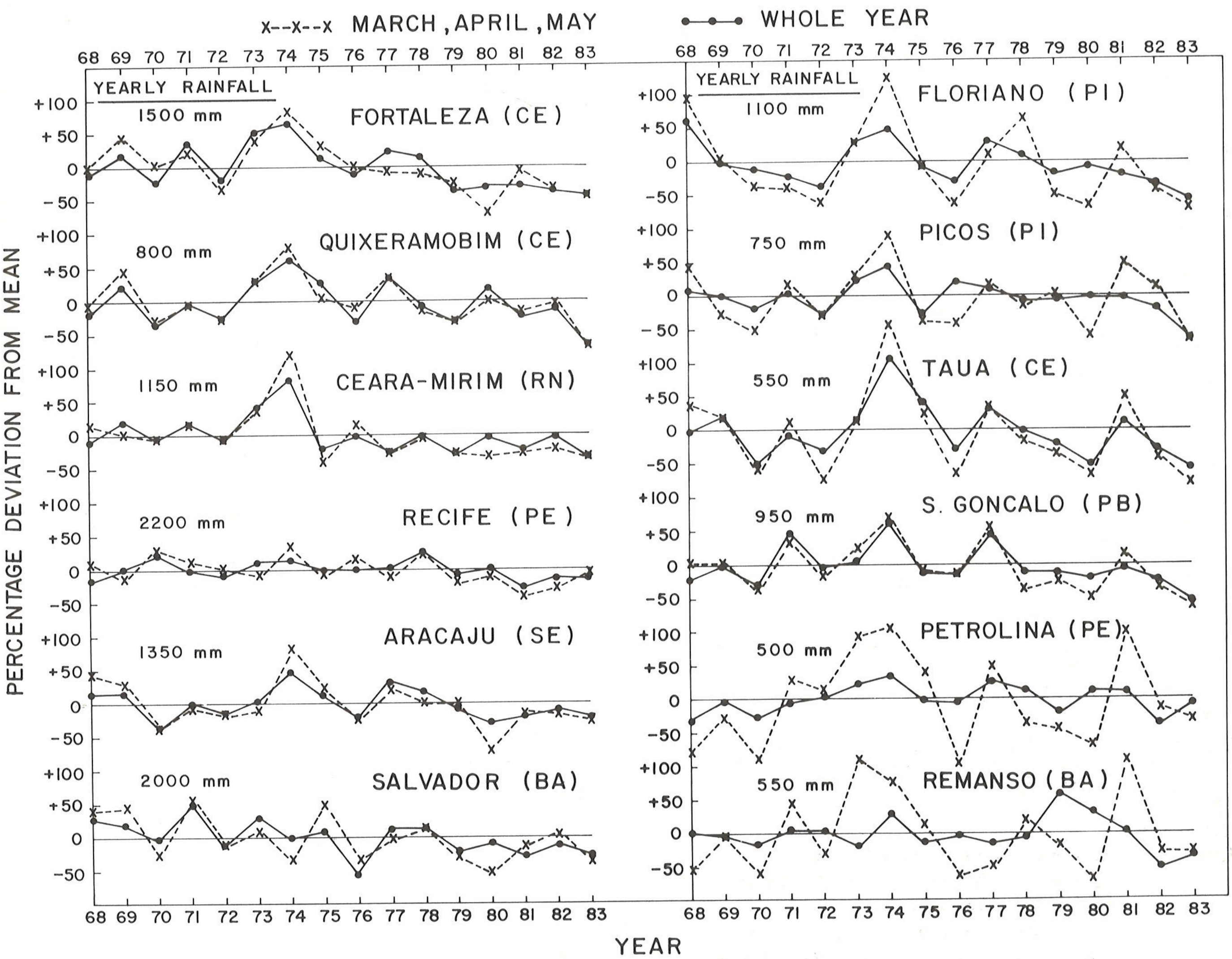

Figure 2 — Plots of percentage deviation from mean for the rainfall for a few selected locations for 1968-1983. Full lines — Yearly total rainfall. Dashed lines — Rainfall for March, April, May.

The stations 1-20 are the same as those used by Rao & De Britto (1984). These stations are 1 in Maranhão (MA), 3 in Piauí (PI), 7 in Ceará (CE), 2 in Rio Grande do Norte (RN), 2 in Paraíba (PB), 4 in Pernambuco (PE) and 1 in Bahia (BA). We could also get data for another 16 stations and these are given in Table 1 as stations 21-36. Fig. 3 shows a plot for the average variations for the 20 stations used by Rao & De Britto (1984) (Fig. 3a) and for these plus 16 more stations (total 36) (Fig. 3b). Full lines represent yearly total rainfall while dashed lines represent rainfall for the rainy season March-April-May. The top curves are for Method A (Superposition of deviations from mean), the middle curves for Method B (Superposition of percentage deviations from mean) and the bottom curves for Method C (Superposition of units of standard deviation σ). In Fig. 3(a), the dashed middle curve of Method B is directly comparable to Fig. 1(a). As can be seen, the deviation for 1981 is +8% for Method B but is -2% for Method A, while in Method C it is almost zero. Also, in all cases the yearly values are more negative than the rainy season values for both 1981 and 1982, and for yearly values the whole period 1979-1983 (five years) has rainfall *below average,* by 10% or more. In 1983 the deficit was ~-45%.

Table 1 gives the details of the deviations by the three methods (A, B, C) for 1981 and 1982 at all the 36 stations individually. As can be seen, the percentage deviations from mean (Method B) for March-April-May of 1981 are *negative* for many stations; but large positive deviations at a few locations are responsible for giving an

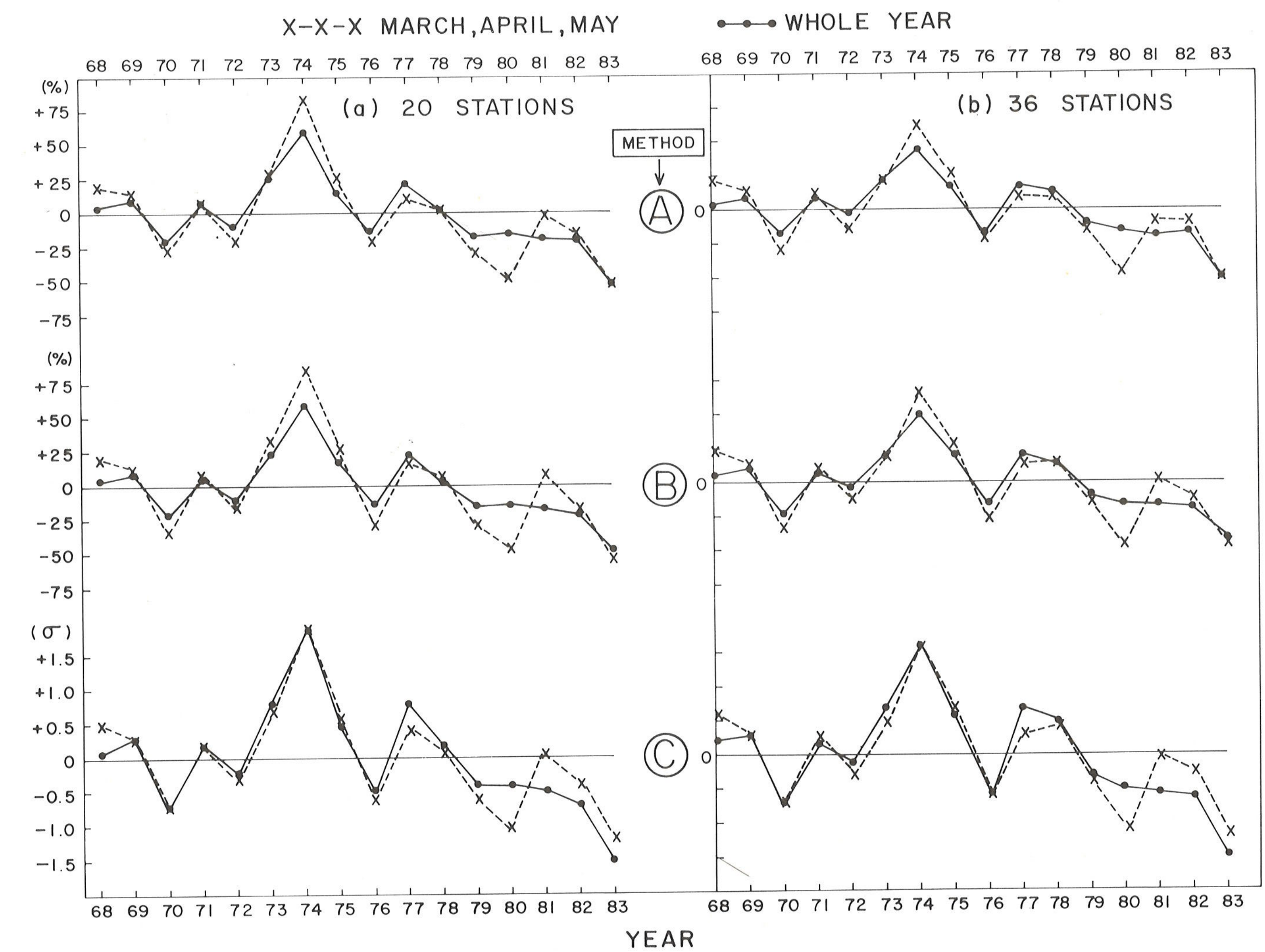

Figure 3 — Plots of the average rainfall for 1968-1983:
(a) Average of 20 stations of Rao & De Britto (1984);
(b) Average of 36 stations;
Top curve — Method A — Superposing deviations from Mean;
Middle curve — Method B — Superposing (%) deviations from Mean;
Bottom curve — Method C — Superposing in units of std. deviation;
Full lines — Yearly total rainfall;
Dashed lines — Rainfall for march, April, May.

average positive deviation. Fig. 4 shows the percentage deviation versus average rainfall for 1981 for the rainy season (upper half) and for the yearly totals (lower half). The predominance of large positive deviations for locations of low rainfalls is clearly seen when only rainy season (Mar.-Apr.-May) values are considered. Five locations, viz. Remanso, Petrolina, Taua, Picos and Água Branca contributed very large positive deviations for the rainy season of 1981. In Table 1 some values are manipulated and hence approximate. These are marked with an asterisk (*), and in Fig. 4 the corresponding points are marked with a question mark (?). However, omitting these values from the analysis did not make any difference to the main conclusions. The 20 stations chosen by Rao & De Britto and the 16 more chosen by us are from various parts of Northeast Brazil. Hopefully, these are fairly representative of the Northeast as a whole. For us, the choice was guided mainly by the availability of data as published in the publications "Monthly Climatic Data for the World" and "Boletins Agroclimatológicos do Instituto Nacional de Meteorologia". Data for about a dozen more stations were also available; but these had many gaps and hence were not useful for this analysis.

We conclude that, in spite of the heavy downpour in March 1981 all over the Northeast, the yearly total rainfall for 1981 was *below normal,* by about 10-15%.

In the earlier publication Kane & Trivedi (1984), it was mentioned that whereas prediction of yearly rainfall at Fortaleza was unreliable, the 5-year moving averages could be predicted with a good deal of certainty. Figure 5 shows the plot of the observed (dots and full lines) and expected (dashes and crosses) values of the 5-year moving averages. A minor drought during 1993-1996 and a major drought during 2003-2010 are indicated.

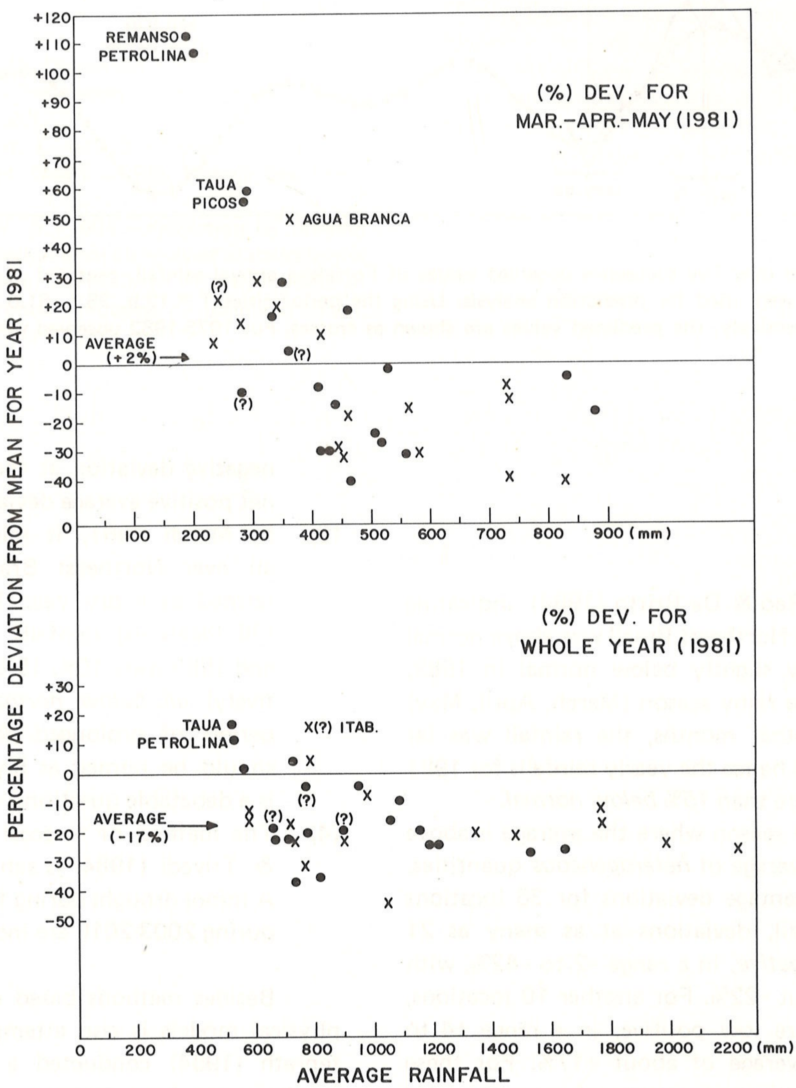

Figure 4 — Percentage deviations from mean for 1981 versus the average rainfall for the rainy season months (upper half) and for the whole year (lower half) for the 20 stations of Rao & De Britto (1984) (dots) and for other 16 stations (crosses). Points with a question mark (?) are approximate.

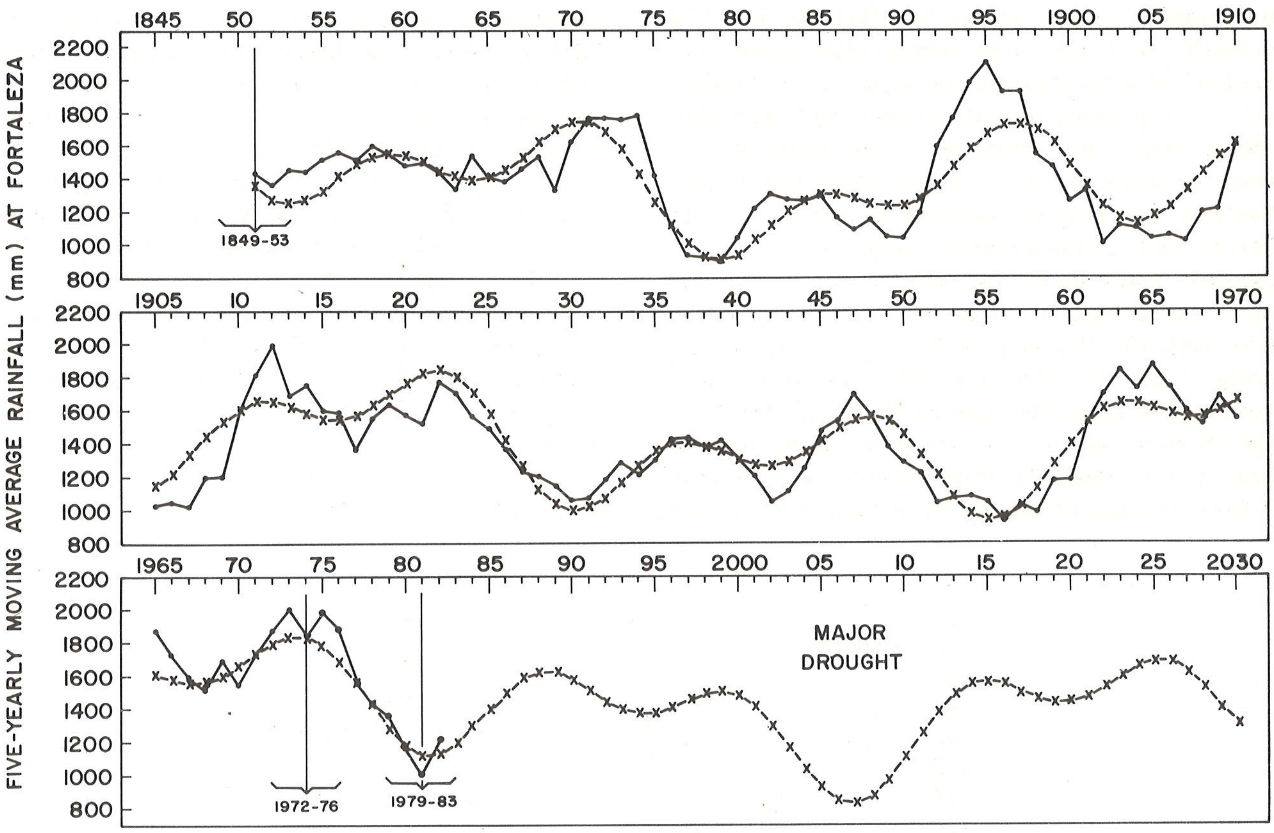

Figure 5 — Moving average over five successive observed values of Fortaleza annual rainfall, centered at years 1851, 1852 . . . 1974 (full lines), which were used for prediction analysis. Using the periodicities T = 12.9, 25.1, 61.0 years with amplitudes 192, 225, 164 mm, respectively, the predicted values are shown as crosses. For 1975-1982 observed values are shown with big dots and full lines.

CONCLUSION

To summarize:

(1) The evidence of Rao & De Britto (1984), indicating that the rainfall in Northeast Brazil was above normal in 1981 and only slightly below normal in 1982, applies only to the rainy season (March, April, May) rainfall. In the other months, the rainfall was far below normal, and hence the yearly rainfalls for 1981 and 1982 were more than *15% below normal.*

(2) Even for the rainy season where the average is above normal, it is an average of *heterogeneous* quantities. Amongst the percentage deviations for 36 locations in Northeast Brazil, deviations at as many as 21 locations were *negative,* in a range -2 to -42%, with an average of about -22%. For another 10 locations, the deviations were low positive, in a range +4 to +28%, with an average of about +17%. For these (21+10) = 31 locations together, the average was still negative, about -10%. Only for 5 locations (all in arid regions) the deviation was large positive, in a range +49 to +107%, with an average of about +77%. This was enough to compensate for the average negative deviation at the other 31 stations to give a net positive average deviation of ~+2%.

(3) In March 1981, it rained heavily (200-300 mm) all over Northeast Brazil. Thus, 1981 cannot be termed as a dry year. However, the *yearly* average (36 locations) rainfalls in 1979, 1980, 1981, 1982 and 1983 were 10%, 15%, 17%, 18% and 44% (respectively) *all below normal.* Thus, this *was* a 5-year period of prolonged *deficit* rainfall. Whether this should be termed as 5-years of continuous drought is a debatable question.

(4) The method of forecast we have described in Kane & Trivedi (1984) is satisfactory over 5-year periods. A minor drought during 1993-1996 and major drought during 2003-2010 are indicated.

Besides methods based on series analysis, a study of physical models is also attempted by some workers. Hastenrath (1984) conducted a multiple regression analysis involving sea level pressure, sea surface temperature and the zonal and meridional components of wind over the tropical Atlantic, and found the analysis useful for predicting droughts in Northeast Brazil with an antecedence of a few months. However, he did not predict the severe drought of 1983. Nobre & Moura (1984) have noticed the existence of wave train patterns teleconnecting the tropical North Atlantic region and other parts of the globe during extreme precipitation events in Northeast Brazil, which could be used for forecasts with a precedence of a few months. From the data available in Nov.-Dec. 1983, these authors had indicated a possibility of excess rain in 1984, which has come true. In private conversation we were informed that preliminary analysis indicated that 1985 may also have rainfall above normal. This seems to have come true.

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