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# THE RAINFALL TREND OVER CEARA AND ITS IMPLICATIONS

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## 1. INTRODUCTION

The Ceara State is located in the Northeast of Brazil, which presents a rainy season centered on the months of March and April as show at table 1. This peculiar rainy season can be explained by the migration towards South, crossing the line of the equator, of the Intertropical Convergence Zone (ITCZ). In these months the ITCZ reaches its more southerly latitude in reaction to the surface characteristics, such as the interhemispheric gradient of Sea Surface Temperature (SST) of the Atlantic Ocean (Hastenrath and Druyan, 1993; Chang et al., 2000). The interannual variability of the precipitation in the Northeast of Brazil has an influence on the anomalies of SST in the Equatorial Atlantic Ocean (Moura and Shukla, 1981) and through teleconection with anomaly of SST of the Equatorial Pacific Ocean, El-Nino, (Uvo et al. 1998)

The work of Haylock et al (2004) investigating the precipitation trend in South America over period of 1960 to 2000 only used the data of 3 rainfall stations in the Ceara. Crato and Aquiraz had presented a reduction trend of the Total Annual Precipitation (PRCPTOT) and Iguatu an increase trend PRCPTOT. These trends had not significant with $p<0,05$.

The report of the "The Intergovernmental Panel on Climate Change" (IPCC) available at the webpage http://www.grida.no/climate/ipcc_tar/wg1/077.htm shows the precipitation trend in diverse regions of the globe on a grid of 5° x 5°. The figure 2.25(ii) shows a trend of reduction of the annual precipitation on the Northeast of Brazil of 8% per decade in the period of 1976 to 1999.

This work investigates the precipitation trend on the Ceara State in the period of 1961 to 2003 and 1971 to 2000. The period 1961 to 2003 was defined aiming to gather the biggest temporal series with the larger number of rainfall stations available in this state. The period of 1971 to

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2000, showing a similar trend, was used to investigate the causes of the observed modifications through atmospheric numerical simulation.

## 2. RAINFALL DATA

Ceara State has hundreds of rainfall stations, but they present different periods of data collection of questionable quality. This work was done using the largest number of Ceara availble stations aiming to reach sounder evaluation of the trend precipitation that the previous ones having a smaller number of isolated stations. Furthemore there is here an additional resource: the analysis of the space variability.

The used precipitation data had been gathered merging diverse data sets of stations from FUNCEME, CPTEC and INMET. The INMET was monthly base and the others daily base. The daily data had been transformed into monthly since that absence of the information in any day did not happen and the maximum daily value was lower then 300 mm. With these criterions was possible to gather 600 rainfall stations with different collection periods.

The monthly precipitation data of the stations had been interpolated to a 0,5 degrees grid, averaging data of the stations contained in each grid point. Figure 1 shows the grid, average number of used stations per grid and the contour of the municipal districts. The grid points with more stations are associates with grid points with smaller municipal district. It is a historical tendency to install at least one rainfall station for each municipal district. A few grid points do not show the average number of stations because along period analysed one or more months did not have available data.

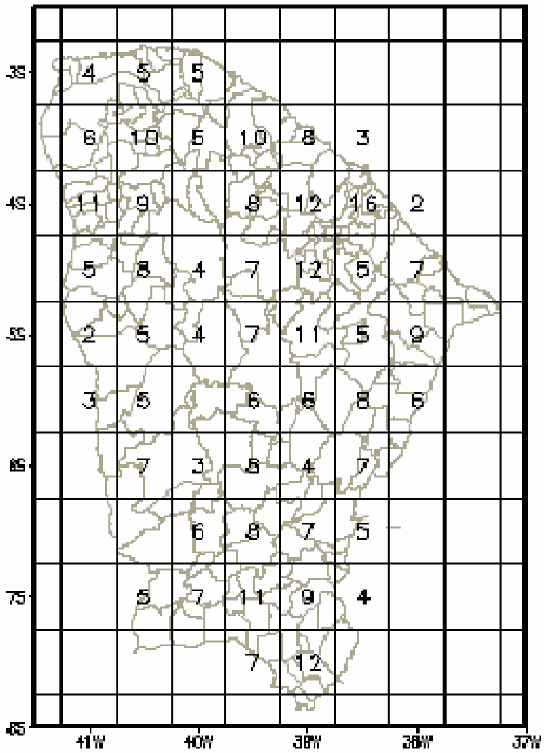


*Figure 1. Ceara State Map showing the grid point of 0,5°, the contour of the municipal district and the average number of used rainfall stations in each grid point used to analyse the precipitation in the period from 1961 to 2003.*

We define the Ceara Monthly Rainfall Index (CMRI) as the grid points average of the precipitation to prevent attributing a greater weight to regions with larger density of stations. The monthly and annual climatology is shown in table 1. It was observed that 85% of the annual total of 872 mm happens in the period of January to May, March and April having the higher monthly climatology precipitation.

*Table 1: Monthly and annual rainfall (mm) Ceara climatology of precipitation over the period of 1961 to 2003*

| month | Jan | Feb | Mar | Apr | May | Jun |
|---|---|---|---|---|---|---|
| Rain | 97 | 131 | 217 | 198 | 103 | 44 |

| month | Jul | Aug | Sep | Oct | Nov | Dez |
|---|---|---|---|---|---|---|
| Rain | 22 | 6 | 5 | 6 | 10 | 33 |

With regard to space distribution (figure 2), the grids points with higger values ( > 800 mm) are associates with fixed local forces, such as:

-Effect of the terrestrial-maritime breeze next to the coast

-The Mountain ranges to the Ibiapaba in the part the north-west, Baturite (4,5° S, 39,0° W), Chapada of the Araripe in the south, and the other having a significative topography (not shown hear).

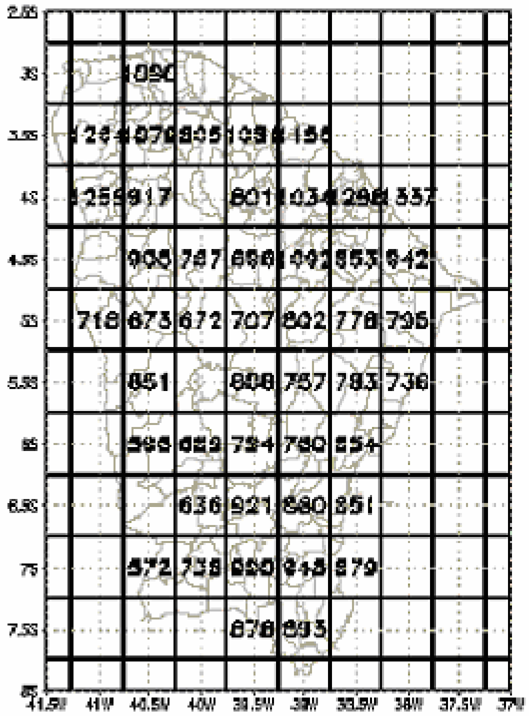

*Figure 2. Annual precipitation climatology (mm) in each grid for the period of 1961 to 2003.*

**3. EVALUATION OF THE TREND OVER CEARA**

In this work the trend is defined as the inclination of the straight line better adjusted in the temporal series of rain data, the adjustment being made by the method of the squared minimum.

From the CMRI the total annual precipitation was series created (figure 3). The reduction trend of the annual precipitation find over Ceara State is 5,3mm/year (6% per decade), where the calculated parameters have a level of significance of 0,1% in test t of Student.

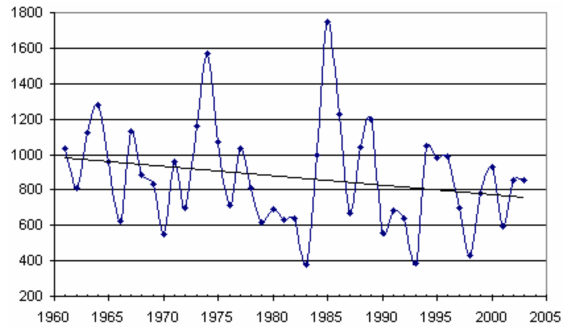


*Figure 3. Temporal evolution of annual precipitation (mm) of Ceara State calculated from the CMRI over period of 1961 to 2003, in blue. The black straight line shows to the reduction trend of rain precipitation adjusted by squared minimum method and the equation of the straight line, where the slope (-5,3) represents the trend of the precipitation in mm/year.*

To verify the consistency of the reduction trend over this period, the trend in each temporal series of each point was calculated. All over the 52 points occurred a reduction trend of the precipitation, showing space consistency of the reduction.

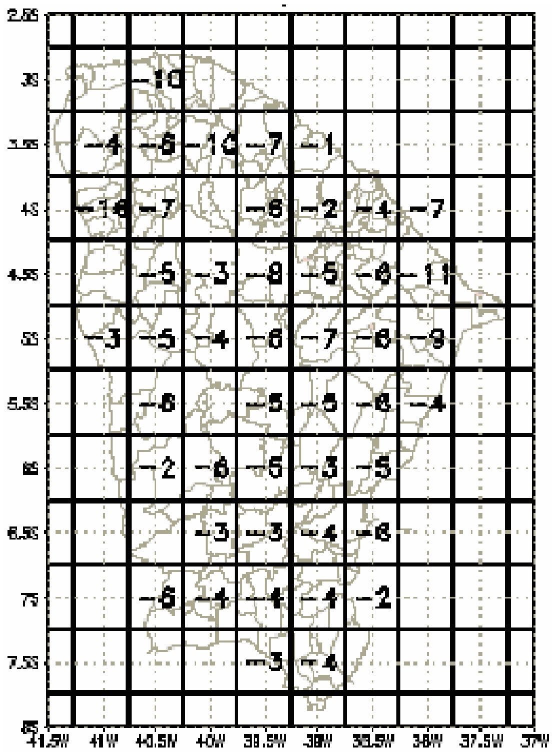

*Figure 4: Annual precipitation trend observed in the period of 1961 to 2003 for each grid in millimeters per year (mm/year).*

The main systems that induce rain at Ceara State are related to the year period. Along January and February months, the Cyclone Upper Level Vortex and the influence of Cold Fronts (CF) that arrive up to the Southern region of Norteast are the main responsible sytems. Along the period of February to May, the ITCZ is the more relevant, and finally along May and June months are the East Waves.

Computing the monthly trend (January to June) from CRMI, in January a increase trend of the precipitation of the order of 5% per decade occurred, all the other months showing a reduction of 5 to 10% per decade, where the calculated parameters have a level of significance of 5% in Student t test. From this it can be inferred that reduction of the annual precipitation observed are related to ITCZ and East Waves. The January precipitation, associated to the Cyclone Upper Level Vortex and the influence of CF, increased.

From FUNCEME data (available from 1974), it had been selected 32 rainfall stations from 1974 to 2003 which had complete daily series in the period, of these sets, 27 presented trend smaller then -2,0 mm/year, 5 stations remained stable (-2,0 the 2,0 mm/year) and 3 showed a trend larger then 2,0 mm/year. It is not casually that the 3 stations showing a precipitation increase are located in the mountain range of Baturite and the mountain range of the Ibiapaba, where the topographic effect, induces this heterogeneous trends on these mountain ranges (Figure 5). The increase of the precipitation in some places of mountain is physically consistent with the reduction trend of rain in the Ceara. The reduction of rain in the Ceara is related to a speed wind increase along the rain periods and also a rain increase due the topographic effect.

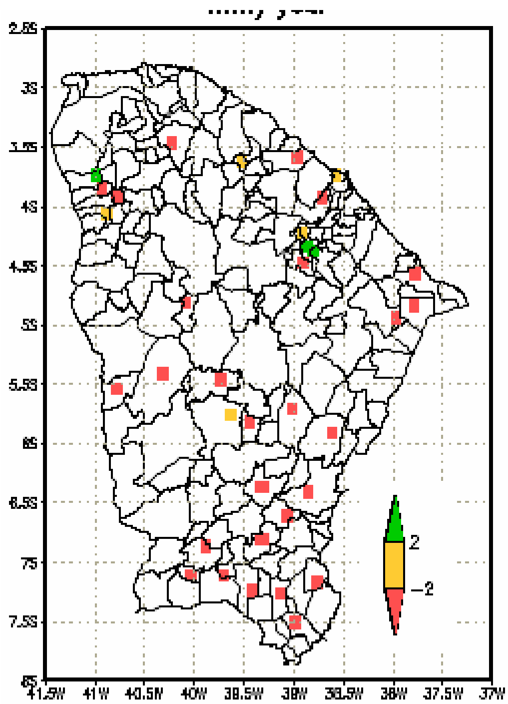

*Figure 5. Annual precipitation trends from 1974 to 2003 from FUNCEME rainfall stations. Red show stations with below -2 mm/year, Yellow show station of -2 to 2mm/year*

*and Green show statios above 2 mm/year. All available stations with complete daily series had been selected.*

## 4. CAUSES OF THE REDUCTION OF THE PRECIPITATION

The interannual and decades variability of the precipitation of the north Northeast of Brazil is related to changes of the SST, more specifically to the equatorial regions of the Ocean Pacific and Atlantic (Hastenrath and Heller, 1977; Moura and Shukla, 1981; Alves and Repelli, 1992).

Here it is investigated the existence of a tendency in the index of Nino 3,4 in the season March to May. The monthly index used was obtained from "Climatic Prediction Center" (CPC) on 5°N-5°S and 170°-120°W and the El-Nino definition occurrence the CPC's one: the average of three consecutive SST anomaly months should be equal or superior 0,5°C in the area of the Nino3.4 using as climatology 1971 to 2000. The CRMI show larger correlation with the Nino 3,4 at March, April and May (Table 2). Following this definition, El-Nino years were (Figure 6) 1966, 1969, 1983, 1987, 1992, 1993 and 1998.

*Tabela2: Correlation coefficients between CMRI and Nino3.4 in the period of 1961 to 2003.*

| | Jan | Feb | Mar | Apr | May | Jun |
|---|---|---|---|---|---|---|
| Correl | -0,15 | -0,12 | **-0,43** | **-0,57** | **-0,59** | -0,10 |
| | Jul | Aug | Sep | Oct | Nov | Dec |
| Correl | -0,33 | -0,02 | -0,28 | 0,05 | -0,05 | -0,10 |

From the temporal evolution analyses of El-Nino 3.4 one can notice (figure 6) an increase of frequency and intensity of the El-Ninos in the period from 1983 to 2003 when compared with the period from 1961 to 1982. There is a sligh heating trend (0,008), although it is not significant in t Student test at a level of 5%.

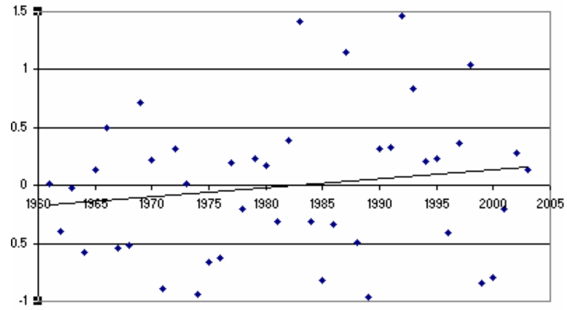


*Figure 6: Temporal evolution of the SST anomaly (Celcius) of El-Nino3.4 for season March to May (points in blue). The anomaly was calculated over climatology of the period of 1971 to 2000. ( SST data from CPC). The black straight line shows an increasing trend, adjusted for the method of the squared minimum to a straight line.*

The rainfall trend could be associated to high frequency and intensity of El-Nino years. It was also analysed the precipitation trend excluding the years of El-Nino (figure 7) where one verifies an absolute decrease of the reduction trend, however the reduction trend remains significant (-3,9 mm/year), where the calculated parameters have a level of significance of 0,1% in t Student test. According to this to these facts, the precipitation reduction trend can not be only justified by the increase of the frequency and the intensity of El-Nino.

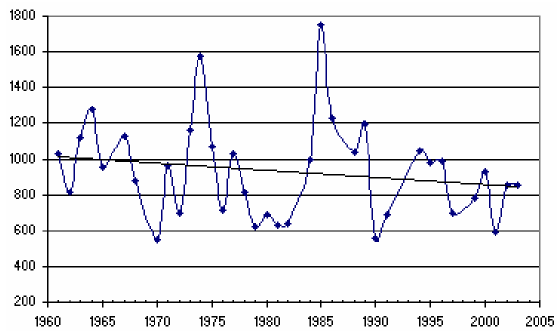

*Figure 7: Temporal evolution of Ceara annual precipitation, excluding El-Nino years (1966, 1969, 1983, 1987, 1992, 1993 and 1998) calculated from the CMRI in the period from 1961 to 2003 in blue. The black straight line shows to the trend of reduction of the precipitation adjusted for the method of the squared minimum and the equation of the straight line, where the inclination term (-3,9) represents the trend of the precipitation in mm/year.*

**5. NUMERICAL SIMULATION**

All the mentioned precipitation trends in the period from 1961 to 2003 are similar to the one's of the period from 1971 to 2000 (not shown until the moment), although have different values. As the numerical experiments were available from 1971 to 2000 (Sun et al., 2004, Moncunill et al 2004), further considerations are developed for this shorter period.

To investigate the cause of the reduction trend at regional scale, a couple of Global Model (AGCM) with regional one was used, assuming the regional forced unidirectional in the entire domain for the information generated for the AGCM. The AGCM was forced by observed SST from "Optimum Interpolation" (Reynolds & Smith, 1994). More details can be found in Sun et al., 2004, Moncunill et al 2004.

This simulation is able to capture quite well the observed precipitation trend, showing not only similar values to the one's observed in Ceara State (figure 8), but keeping also the same gradient tendency South-North.

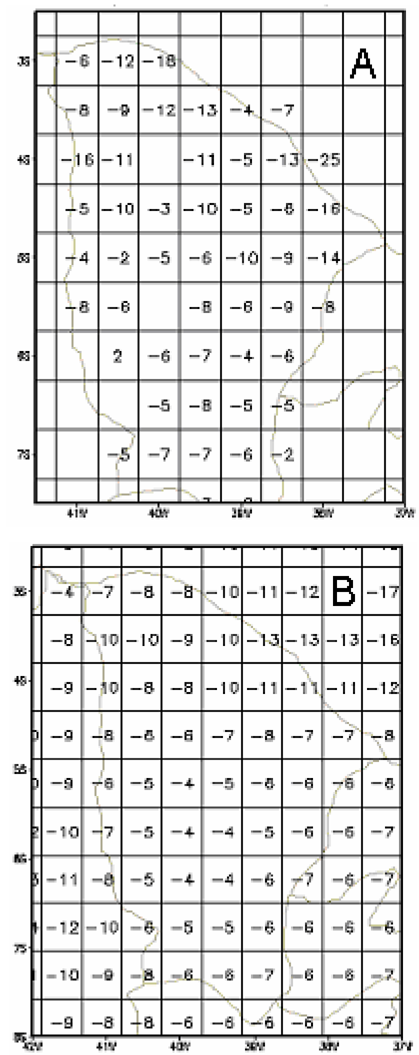


*Figure 8. Trend in the period of 1971 to 2000 for seasonal precipitation (January to June) in millimeters per year. Calculated from the precipitation observed over a grid of 0,5° b) calculated from the simulation.*

The simulation suggests that the primary force that provoked the reduction of the precipitation in the period was not by a local or regional forced by change of the covering surface in function of that had remained constant in the simulation. The trend was generated by changes on SSTs at global scale.

It was calculated the trend of the simulation excluding the El-Nino years (not shown), a trend of reduction of the precipitation was still observed. From this result one may suggests that, beyond El Nino other SST alteration would be associates with the precipitation reduction.

In figure 9 it is shown the SST trend calculated from the data of Reynolds & Smith, in the season March to May on the Pacific and Atlantic equatorial Oceans, regions that show correlation with the interannual variability of the Northeast precipitation. Trend of heating in the area of El Nino, shown in the previous section, and in the area of the Equatorial Atlantic is observed trend of bigger heating in the north basin greater than south basin. The trend observed at north Equatorial Atlantic basin is strong relate to the period. The 1976/77 Pacific Decadal Oscilation (PDO) phase change can be related to changes at SST and could be the main reason for observed rainfall trend, but futher investigation is necessary.

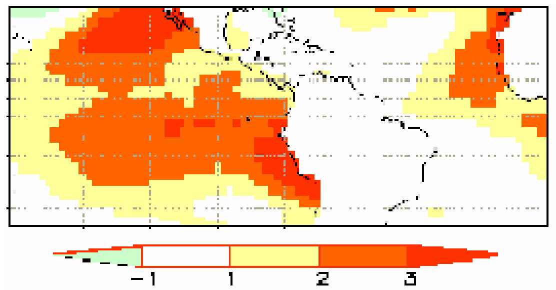


*Figure 9. SST observed trend at period of 1971 to 2000. Calculated from the data of "Optimum Interpolation" (Reynolds & Smith, 1994). Unit is Celsius per century for season march to may.*

Figure 10 shows the precipitation simulated rainfall trend in the domain of the regional model. One can notice on the tropical basin of Atlantic Ocean a trend of the ITCZ to be more dislocated for the hemisphere north in the period of January the June. Also there is a rainfall reduction trend over all Northeast and alterations in the part of African continent. The trend simulated in the NE and part of Africa is similar to one reported of the IPCC (http://www.grida.no/climate/ipcc_tar/wg1/images/fig2-2ïi.gif), although the period shown in the IPCC is for 1976 to 1999.

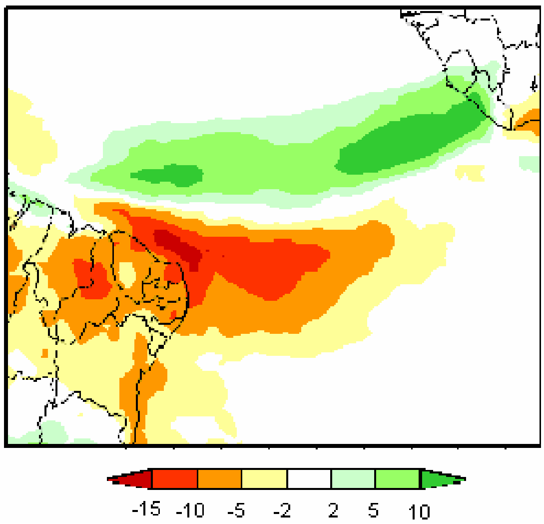


*Figure 10. Trend in the period of 1971 to 2000 for season precipitation (January to June) in millimeters per year simulated by ECHAM4.5/RSM97 forced by observed SST. The yellow colours for red represent reduction of precipitation and in green trend of increase.*

## 6. CONCLUSION

In the period of 1961 to 2003 was observed negative trend of the annual precipitation over Ceara of 6% per decade, however in January's months occurred an increase 5% per decade. The reduction occurred in practically all the regions of the state, excluding a few areas, where the precipitation is more dependent of the topography. In these small few areas alternation of the trends was observed.

The increase of the frequency of El-Ninos on one side, and the trend of larger heating on the North basin then the South basin of the Tropical

Atlantic Ocean on the other side, are the main ones responsible for the rain reduction in Ceara State. The PDO phase change at 1976/77 is related to the observed SST trend.

In the simulation was observed that ITCZ had a tendency to be displaced Northward, result that is consistent with the trend of higher heating of SST at Equatorial North Atlantic in relation the South basin and the precipitation reduction in the Ceara. One may assume the reduction occurred in all the Northeast of Brazil, and that occurred because a trend of the ITCZ of the Atlantic Ocean was more dislocated to northward during rain seasons of Northeast of Brazil.

**BIBLIOGRAPHY**

Alves, J. M. B.; C.A. Repelli: 1992:. A variabilidade pluviométrica no setor norte do nordeste e os eventos El Niño/Oscilação Sul (ENOS). Rev. Bras. Meteor., v.7, n.2, p.583-592

Chang, P., R. Saravanan, L. Ji, and G. C. Hegerl, 2000: The effect of local sea surface temperatures on atmospheric circulation over the tropical Atlantic Sector. J. Climate, 13, 2195-2216

Hastenrath S; L. Hellers. Dynamics of climatic hazards in northeast Brazil. Q. J. Roy Meteor. Soc., 103, 77-92.

Hastenrath, S., and L. Druyan, 1993: Circulation anomaly mechanisms in the tropical Atlantic sector during the Northeast Brazil rainy season. J. Geophys. Res. - Atmospheres, 98, 14917-14923

Haylock M. R., Peterson T., Abreu de Sousa J. R. , Alves L. M., Ambrizzi T., Baez J.g,Barbosa de Brito J. I., Barros V. R., Berlato M. A., Bidegain M., Coronel G., Corradi V.,Grimm A. M., Jaildo dos Anjos R., Karoly D., Marengo J. A., Marino M. B., Meira P. R.,Miranda G. C., Molion L., Moncunil D. F., Nechet D., Ontaneda G., Quintana J., Ramirez E.,Rebello E., Rusticucci M., Santos J. L., Varillas I. T., Villanueva J. G., Vincent L., Yumiko M., 2006: Trends in total and extreme South American rainfall 1960-2000 and links with sea surface temperature. Journal of Climate, 19, 1490-1512.

Moncunill, D.F, L. Sun; A. D. Moura;. E. M. Silva; V. Silva Filho; W. L. B. Melcíades; A. A. Costa; P. Nobre 2002:Uma Breve Descrição do Sistema de Previsão Climática Regionalizada (Downscaling Dinâmico) Implantado na Funceme. Anais of- XII Congresso Brasileiro de Meteorologia,

Moura, A.D.; J. Shukla: 1981: On the dynamics of droughts in northeast Brazil: Observations, theory and numerical experiments with a general circulation model. Jour. Atmos. Scie, 38(7): 2653-2675.

Sun, L., D. F Moncunill, H. Li, A. D. Moura and F. A. S. Filho: 2005: Climate Downscaling over Nordeste Brazil using NCEP RSM97. Journal of Climate, 18, 551-567.

Uvo, C. R. B., C. A. Repelli, S. E. Zebiak, and Y. Kushnir, 1998: On the relationships between tropical Pacific and Atlantic SST in northeast Brazil monthly precipitation. J. Climate, 13, 287-293.