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TWO ENSO EPISODES WITH REVERSED IMPACTS ON THE REGIONAL PRECIPITATION OF THE NORTHEASTERN SOUTH AMERICA

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ABSTRACT

Diagnostic analyses of two ENSO episodes observed during 1954-55 (La Niña) and 1972-73 (El Niño) over tropical Pacific Ocean are reported. These years were marked by reversed impact on the regional precipitation observed over the northeastern South America. The observational results showed that, in the Pacific Ocean, the La Niña stayed well configured during both summer and autumn of 1954-55, however the El Niño presented its mature phase during summer of 1972-73 and an abrupt decline during autumn of 1973. On the other hand, the large-scale oceanic and atmospheric patterns related to the intertropical Atlantic SST gradient, created dynamic conditions that modulated the positioning of ITCZ in the equatorial Atlantic and regulated significantly the rainfall anomalies observed in the northeastern South America, overcoming the effect of the ENSO mode observed in the tropical Pacific.
Key words: ENSO, Atlantic SST Gradient, ITCZ, South America

DOS EVENTOS ENSO CON IMPACTOS OPUESTOS SOBRE LA PRECIPITACIÓN REGIONAL EN EL NORESTE DE SUDAMÉRICA

RESUMEN

En el presente trabajo se realiza un estudio de diagnóstico de los eventos ENSO ocurridos en 1954-55 (La Niña) y 1972-73 (El Niño). Durante 1954-55 (1972-73), se observaron anomalías de temperaturas de la superficie del mar (TSM) positivas (negativas) en el Atlántico Norte y negativas (positivas) en el Atlántico Sur, lo que define la fase positiva (negativa) del dipolo Atlántico. Los resultados obtenidos muestran que pese a la ocurrencia del evento La Niña (El Niño) en el Pacífico, la configuración del dipolo positivo (negativo) en el Atlántico creó las condiciones favorables para mantener la ITCZ al norte (sur) del Ecuador. En consecuencia, se encontró un déficit (exceso) de precipitación en el nor-noreste brasileño durante DEF y MAM de 1954-55 (1972-73). Por lo tanto, durante estos años la configuración anómala de TSM en el Atlántico moduló las anomalías de lluvia observadas en el Amazonas y noreste de Brasil, superando el efecto del ENSO.
Palabras clave: ENSO, Gradiente de TSM en el Atlántico, ITCZ, América del Sur

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1. INTRODUCTION

There is a large consensus in the scientific community that the El Niño-Southern Oscillation (ENSO) cycle is considered one of the most prominent sources of interannual variations in weather and climate around the world (Trenberth and Caron 2000). Several studies have shown that ENSO events are associated with changes in the general circulation of the atmosphere, which result in global climate impacts (Trenberth 1991). In particular, areas located at the northeastern South America (including Venezuela, French Guiana, Surinam, Guyana and Brazilian Amazon and Northeast regions) have one of the most consistent ENSO-precipitation relationships (Ropelewski and Halpert, 1987). Some authors (e.g., Kousky et al 1984; Aceituno 1988; Rao and Hada 1990; Alves and Repelli 1992; Uvo et al 1998; Coelho et al 1999; Souza and Ambrizzi 2002; among others) reported observational evidences that the El Niño (La Niña) years are related to the occurrence of deficient (abundant) rainy season in these continental areas.

Nevertheless, others studies have shown that the tropical Atlantic Ocean also plays an important role in the interannual variability of the rainy season of the eastern Amazon and northeast Brazil (Hastenrath and Heller 1977; Moura and Shukla 1981; Nobre and Shukla 1996; Uvo et al 1998; Souza et al 2000 and others). The quality of the rainy season in these regions is remarkably modulated by the displacement of the cloudiness and precipitation band associated with the Intertropical Convergence Zone - ITCZ (Nobre and Shukla 1996; Souza et al 1998). ITCZ reaches its southernmost position in the equatorial south Atlantic around March (Hastenrath and Lamb 1977; Waliser and Gautier 1993), occasion in which is observed the peak of the eastern Amazon and northeast rainy season. The latitudinal position of the ITCZ is strongly dependent of the so-called interhemispheric meridional sea surface temperature (SST) gradient, which hydrostatically controls the sea level pressure (SLP) and the wind patterns over the equatorial Atlantic Ocean (Hastenrath and Greischar 1993; Nobre and Shukla 1996; Wagner 1996; Souza and Nobre 1998, Hastenrath 2002). Such interhemispheric gradient is considered the dominant mode of the climate variability in the tropical Atlantic during austral autumn (Servain 1991; Nobre and Shukla 1996). Basically, a northward (southward) SST gradient is established in the equatorial Atlantic, when the tropical north/south Atlantic simultaneously present positive/negative (negative/positive) SST anomalies. Thus, a rainy season anomalously wetter (dryer) is observed over eastern Amazon and northeast Brazil under conditions closely associated with such southward (northward) interhemispheric SST gradient.

Modelling studies by Lau and Nath (1994) and Lau (1997) showed that the changes of tropical Atlantic SST during El Niño years are forced by changes in atmospheric circulation, suggesting that both are driven by changes in the Pacific SST. More recently, Pezzi and Cavalcanti (2001) used an atmospheric global model to investigate the relative importance of the tropical Pacific and Atlantic SST anomalies on the Brazilian northeast rainy season. They found that El Niño conditions in the Pacific and a northward SST gradient in the intertropical Atlantic resulted in negative precipitation anomalies over the northeast Brazil. A sign reversal (positive precipitation anomalies over the northeast) was found persisting the same El Niño condition in the Pacific and a southward SST gradient in the Atlantic. On the other hand, when La Niña conditions were tested together with a southward (northward) SST gradient in the Atlantic, a rainy season anomalously wetter (dryer) occurred in the Brazilian northeast.

Therefore, based on previous observational studies we can nowadays assure that ENSO events influence the precipitation patterns over South America, where the north and northeast of Brazil seems to show one of the strongest signals. However, numerical studies have suggested that the tropical Atlantic may be important to modulate the seasonal precipitation pattern over the northeastern South America. Thus, this work presents a comprehensive diagnostic analysis of the oceanic patterns associated with the La Niña 1954-55 and El Niño 1972-73 episodes, which were marked by reversed impacts in the regional precipitation of the South American northeast when compared to previous observational studies. An observational approach was done so that the large-scale dynamic conditions will be focused, in order to verify the relative importance of the anomalous oceanic and atmospheric patterns in the tropical Pacific and Atlantic on the rainy season of the northeastern South America during these two particular ENSO events.

2. DATA AND ANALYSIS PROCEDURE

The monthly dataset for the 1954-55 and 1972-73 years consist of zonal, meridional and vertical components of the wind vector and specific humidity in the levels of 1000, 925, 850, 700, 600, 500, 400 and 300 hPa, as well as their respective long-term mean, obtained from the NCEP/NCAR reanalysis project (Kalnay et al 1996). These data are disposed in a global grid with spatial resolution of 2.5 degrees in latitude and longitude. The SST data, with spatial resolution of 1 degree in latitude and longitude, were extracted from last version of COADS, compiled by Da Silva et al (1994). Rainfall data registered in the past is difficult to acquire. However we have used the 50-year gauge precipitation data set compiled by Chen et al (2002), who put together a large number of monthly precipitation on a 2.5° latitude/longitude grid over the global land areas for the 1948-2000 period. The gridded field of monthly precipitation was defined by interpolating gauge observations over 15,000 stations collected from the version 2 of GHCN (Global Historical Climatology Network) dataset, using the optimum interpolation algorithm. Additionally, it was used the monthly precipitation records for 32 rain gauge stations dispersed along the northeastern South America. These rain gauge-based data (including the stations located outside Brazil) were obtained from the Instituto Nacional de Meteorologia (INMET) of Brazil. The geographical locations of these stations are shown in Figure 1.

In order to diagnose the large-scale atmospheric and oceanic patterns, several seasonal plots for the austral summer (Dec-Jan-Feb - DJF) and autumn (Mar-Apr-May - MAM) seasons of 1954-55 (La Niña) and 1972-73 (El Niño) were made. To analyze the vertical structure of the tropospheric circulation related to the Walker and Hadley circulation, we have decomposed the divergent wind components from the horizontal wind vector at all pressure-levels. Such divergent part of the wind is essential to study the atmospheric convergence-divergence that drives vertical motion and circulation in the tropics (Hastenrath 2001). Thus, for the analyses of the Walker circulation, zonal cross-sections (longitude x height) of the divergent circulation and specific humidity anomalies averaged along the austral equatorial portion between 10°S and 0° (as shown by SEC1 in the Figure 2) were plotted. Similarly, for the Hadley circulation analyses, meridional cross-sections (latitude x height) averaged in three longitudinal bands (SEC2: 55°W-50°W; SEC3: 45°W-40°W; and SEC4: 30°W-25°W as seen in the Figure 2) along the tropical Atlantic Ocean and South America were plotted.

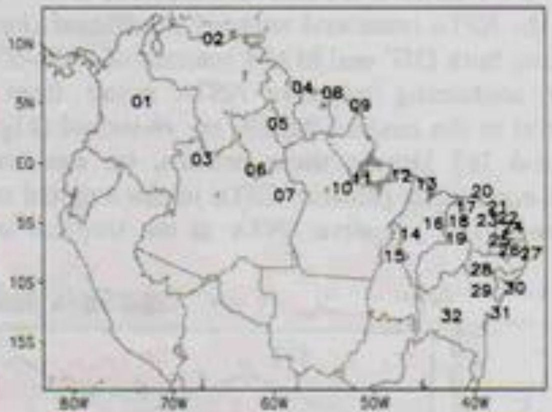

Figure 1: Geographical locations of the 32 rain gauge stations distributed along the northeastern South America.

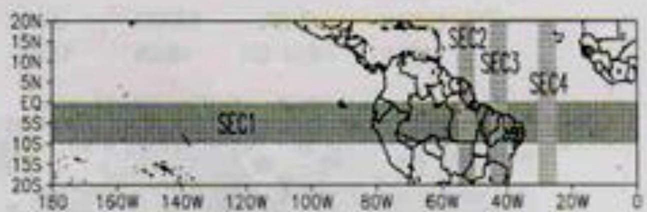

Figure 2: Regions where it was calculated the vertical cross-sections in the east-west direction (SEC1, averaged between 10°S-0°); and in the north-south direction (SEC2, SEC3 and SEC4, averaged between 55°W-50°W, 45°W-40°W and 30°W-25°W, respectively).

3. RESULTS

3.1. SSTs and Precipitation Analyses

The two ENSO episodes observed during 1954-55 (La Niña) and 1972-73 (El Niño) also were identified by Trenberth (1997) and

CPC/NCEP ENSO classification (see online at www.cpc.ncep.noaa.gov/research_papers/ncep_cpc_atlas/8/ensoyrs.txt). The seasonal evolution and the spatial configuration of the SST anomalies (SSTa) during 1954-55 and 1972-73 are shown in the Figure 3.

The typical La Niña characteristics of negative SSTa and positive Southern Oscillation Index (SOI) were observed since spring of 1954 until winter of 1955. During the mature phase of the La Niña, extreme values of SOI and SSTa averaged in the Niño3.4 occurred during DJF of 1954-55 with magnitudes of about 1.5 and –1, respectively (Figure 3a). In the subsequent season (MAM of 1955) we noticed a relative weakness of the SOI, but the SSTa remained without significant change. During both DJF and MAM seasons of 1954-55, an area containing negative SSTa going from the central to the eastern Pacific are observed (Figures 3c and 3e). During these periods, we can see an area containing positive SSTa in the tropical north Atlantic and negative SSTa in the tropical south Atlantic (Figures 3c and 3e). This inverse SSTa pattern is associated with the establishment of the northward interhemispheric SST gradient previously described.

On the other hand, the 1972-73 El Niño event already presented its mature stage during spring and summer of 1972-73, having positive SSTa varying between 1.5 and 2 (averaged in the Niño3 and Niño 3.4) and negative SOI varying between -1.5 and –2 (Figure 3b). From the seasonal evolution of the Niño3 and Niño3.4 and SOI, we can clearly see the abrupt termination of this event during MAM of 1973 (Figure 3b). This is confirmed in the SSTa fields, in which it is clearly verified the strong El Niño configuration over tropical Pacific (Figure 3d) during DJF and its total suppression in the following season (Figure 3f). It is interesting to notice that the SSTa in the tropical Atlantic show a configuration associated with the southward SST gradient associated with negative anomalies in the north Atlantic and positive anomalies in the south Atlantic (Figures 3d and 3f).

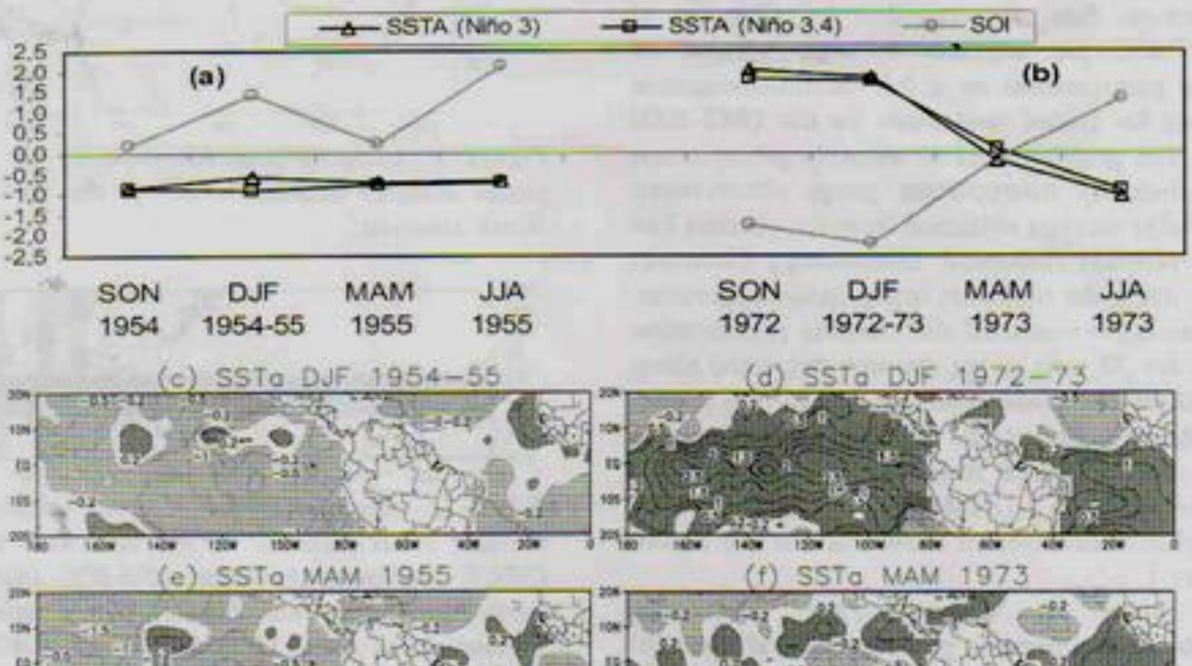

Figure 3: (a) and (b) Seasonal evolution of the SSTa (°C) averaged in Niño3 and Niño3.4 areas (black solid lines) and standardized Southern Oscillation Index – SOI (grey solid line) during 1954-55 and 1972-73; (c), (d), (e) and (f) Spatial configuration of the SSTa (°C) in the tropical Pacific and Atlantic Oceans observed during DJF and MAM of 1954-55 (figures to the left) and 1972-73 (figures to the right). Solid contours with dark shaded represent positive anomalies and the dash contours with light shaded represent negative anomalies.

Figure 4 shows the seasonal percentage deviations of the precipitation observed over the tropical South America during the DJF and MAM of the 1954-55 and 1972-73, respectively. From the previous observational and statistical ENSO studies one would expect that during an El Niño year, the northeastern Brazil should have below normal precipitation during its rainy season and an inverse signal during the La Niña event. However, from Figure 4 we see an essentially reversed pattern. During the La Niña (El Niño) period, a predominance of negative (positive) deviation of precipitation varying between –10% to –40% (+10% to +30%) were observed in the eastern Amazon and in the whole Brazilian Northeast during DJF and MAM of 1954-55 (1972-73). This result indicates that at least for the two ENSO events analyzed here, the Atlantic SST gradient was the large-scale pattern that modulated the precipitation anomalies on the northeastern South America. Thus, it is clear that any general conclusion of ENSO impacts must always be seen with care.

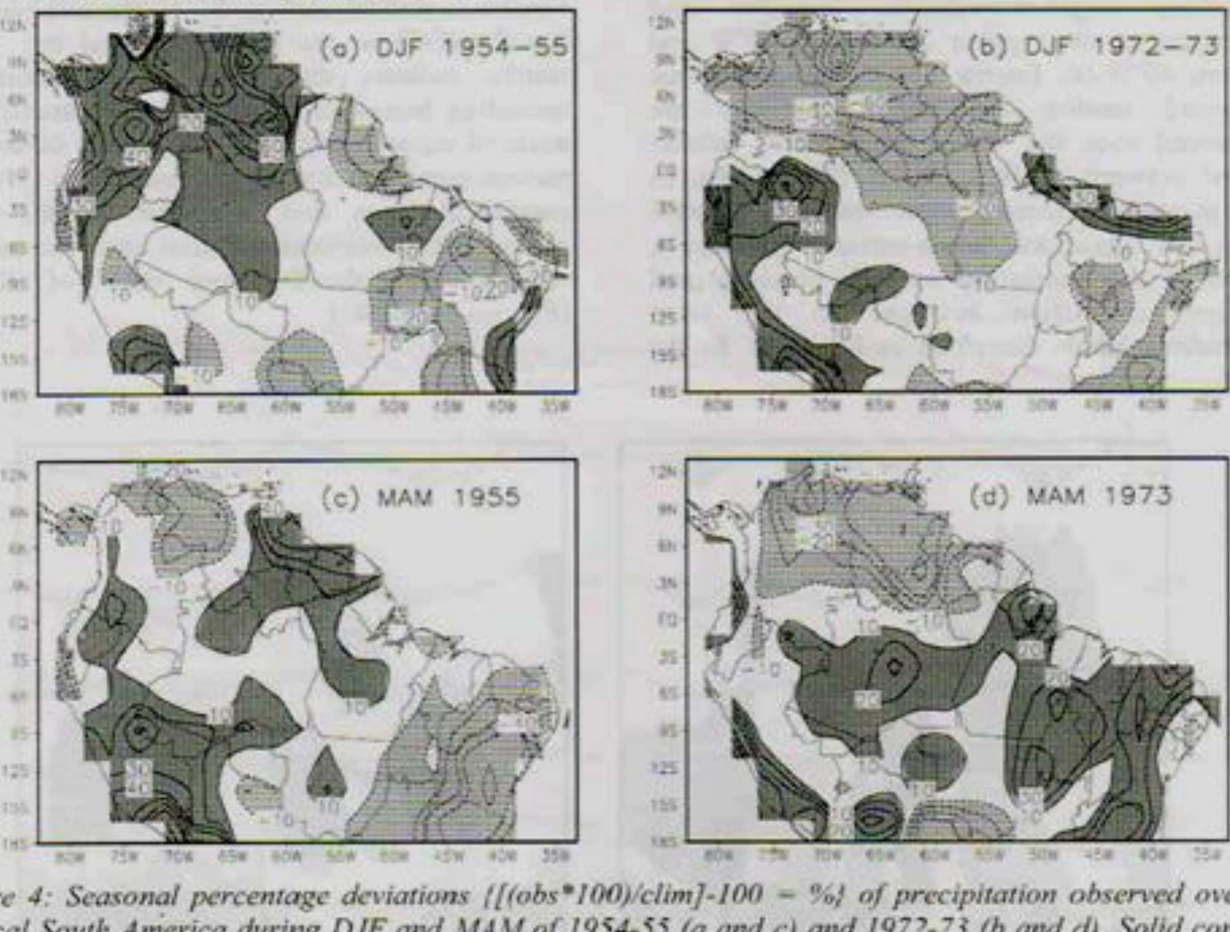

*Figure 4: Seasonal percentage deviations {[(obs*100)/clim]-100 = %} of precipitation observed over the tropical South America during DJF and MAM of 1954-55 (a and c) and 1972-73 (b and d). Solid contours with dark shaded represent positive deviations and dash contours with light shaded represent negative deviations.*

3.2. The Walker, Hadley and ITCZ Circulation Analyses

The anomalous large-scale atmospheric circulation patterns related to Walker and Hadley cells during La Niña 1954-55 are analyzed in the Figures 5 and 6. Figure 5 shows the seasonal zonal cross-sections (longitude x height) of the anomalous specific humidity and divergent circulation averaged between 10°S-0° (see SEC1 in the Figure 2). This circulation pattern represents part of the Walker circulation in the tropical belt along the Pacific and Atlantic Oceans and South America. A prominent presence of anomalous negative specific humidity and descending motion distributed over the whole atmospheric column in the tropical Pacific (from 180° to 110°W, where the abnormally cold waters associated to the La Niña are observed) is noticed during DJF (Figure 5a). In the subsequent season, the maximum descending motion anomalies are shifted eastward, between 120°W to 90°W, indicating an enhancement of the sinking branch of the Walker cell in the eastern Pacific (Figure 5b). In the austral equatorial area between South America and Atlantic Ocean there is a predominance of descending motion anomalies in most of the tropospheric circulation. Significant anomalous negative specific humidity and descending motion appear centred on 80°W and between 40°W-0°. During MAM, the anomalous downward motion and deficit humidity are maximized over the whole tropospheric column centred between 60°W to 40°W (Figure 5b). In order to complete these dynamic analyses, Figure 6 shows the meridional cross-sections (latitude x height) of the anomalous specific humidity and divergent circulation averaged in the three longitudinal bands described in Figure 2. In the SEC4 (Figures 6c and 6f), which takes the north and south basins of the tropical Atlantic, it was observed the manifestation of a thermally direct meridional circulation cell with anomalous ascending branch and humidity excess in the north Atlantic (where SSTs were warmer than normal; see Figures 3c and 3e) and an anomalous descending branch and humidity deficit over the south Atlantic (where SSTs were colder than normal; see Figures 3c and 3e). Such anomalous north-south circulation cell is more evident and stronger in the cross-sections mediated between north Atlantic and eastern Amazon (SEC2 in the Figures 6a and 6d) and north Atlantic and northeast Brazil (SEC3 in the Figures 6b and 6e). These results indicate that there is an anomalous ascending branch of the Hadley circulation to the north of equator, while the anomalous descending motion occurs to the south, specifically over the eastern Amazon and Northeast Brazil, which explains the precipitation deficit observed in these regions during the DJF and MAM of 1954-55 (Figures 4a and 4e).

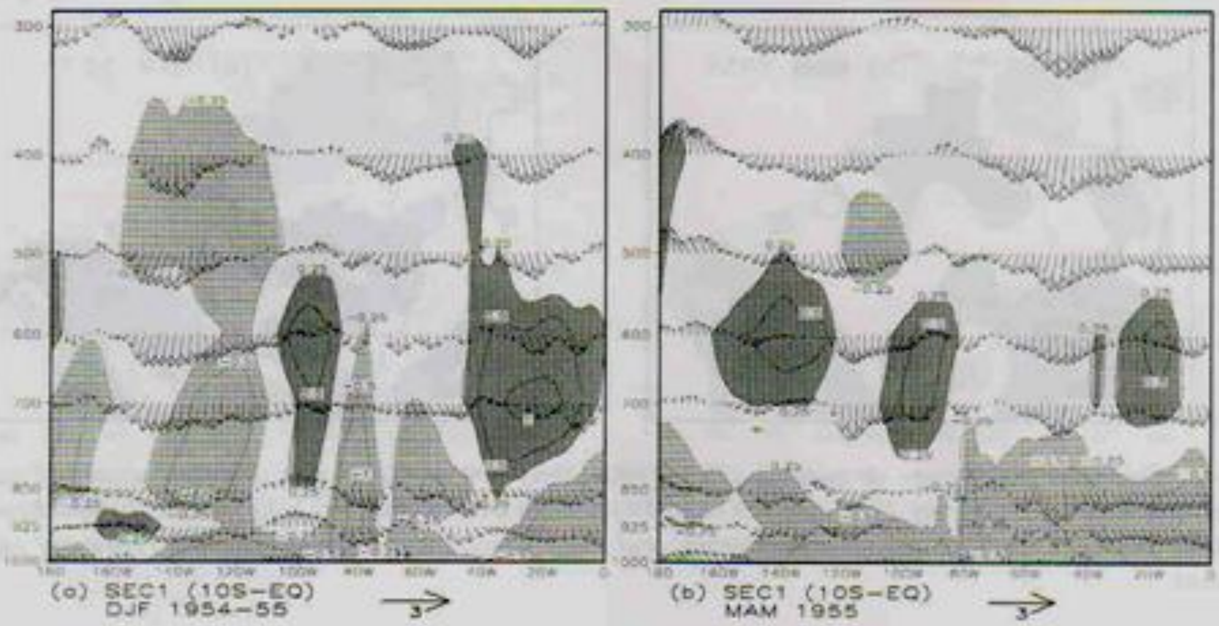

Figure 5: Vertical cross-sections in the east-west direction (longitude x height) of the specific humidity (shaded contours in g/Kg) and divergent circulation (vectors in m/s; 10^{-4} hPa/s) averaged between 10°S-0° (SEC1), for the DJF (a) and MAM (b) of 1954-55. The divergent circulation is represented by vectors of combined divergent zonal wind and vertical velocity. Solid contours with dark shaded represent positive anomalies and the dash contours with light shaded represent negative anomalies.

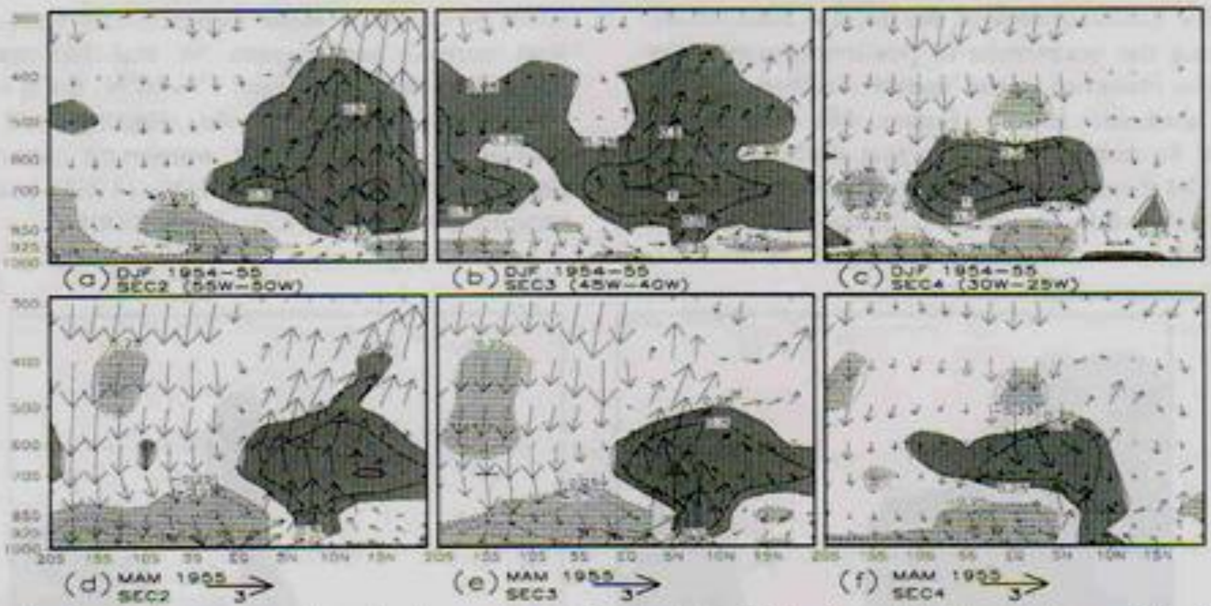

Figure 6: Vertical cross-sections in the north-south direction (latitude x height) of the specific humidity (shaded contours in g/Kg) and divergent circulation (vectors in m/s; 10^{-4} hPa/s) averaged in the three latitudinal bands of 55°W-50°W (SEC2), 45°W-40°W (SEC3) and 30°W-25°W (SEC4), for the DJF (a, b and c) and MAM (d, e and f) of 1954-55. The divergent circulation is represented by vectors of combined divergent meridional wind and vertical velocity. Solid contours with dark shaded represent positive anomalies and the dash contours with light shaded represent negative anomalies.

Similar analyses were applied to diagnose the dynamic conditions related to the 1972-73 El Niño. Analyzing the zonal circulation, the most striking feature observed in DJF (Figure 7a) was the replacement of descending to ascending branch in the Walker cell as well as an excess of humidity in the whole tropospheric column over the central and eastern Pacific (where SSTs were warmer than normal; see Figure 3d). On the other hand, in the zonal circulation pattern over the South America and Atlantic Ocean (Figure 7a), the anomalous tropospheric descending motion centred at 40°W is observed during DJF, indicating the presence of the sinking branch of the Walker cell over that region. On the east and west sides of this descending branch, upward motion and positive humidity anomalies are observed in the lower troposphere between 70°W-50°W and in the lower and middle troposphere between 30°W-10°W. In the meridional tropospheric circulation during DJF, we can see that the more intense downward motion anomalies are verified between 20°S-10°S in both SEC2 and SEC3 (Figures 8a and 8b). Such areas containing large-scale subsidence coincide with the deficit precipitation observed in the southern portion of the Brazilian northeast and Amazon (Figure 4b). In spite of the descending motion anomalies restricted in the higher troposphere over Brazilian northeast region (Figures 7a, 8a and 8b), there is also the presence of ascending motion anomalies in the lower troposphere (Figure 8a). These results suggest that the sinking branch of the Walker and Hadley cells do not influence the lower levels equatorial troposphere and then it explains the occurrence of the positive precipitation anomalies observed in a small portion located at the eastern Amazon and northern northeast Brazil during the summer of 1972-73 (Figure 4b). In the following season, the rupture of the El Niño occurs and the Walker cell configuration presents significant changes in the Pacific Ocean, where is observed a predominance of downward motion anomalies and abrupt decrease of the positive humidity anomalies (Figure 7b). The anomalous descending branch of the Walker and Hadley cells, which in the previous season were over the northeast Brazil, are restricted to the lower levels and centred in 40°W (Figure 7b) and 10°S (Figure 8e) during MAM. Thus, the dominant presence of the ascending motion anomalies in both zonal (Figure 7b) and meridional (Figures 8d and 8e) planes over the tropical Brazilian troposphere favors the establishment of the tropical convection, explaining the occurrence of positive precipitation anomalies observed in the eastern Amazon and the whole northeast Brazil (Figure 4d). The SEC4 (Figures 8c and 8f) indicates that during the DJF and MAM there are upward wind anomalies in the south basin of the tropical Atlantic (where SSTs were warmer than normal; see Figures 3b and 3d), while in the north basin (where SSTs were colder than normal; see Figures 3b and 3d) prevailed downward motion around 5°N-10°N. Such vertical circulations related to the Hadley cell were previously found in the numerical simulations performed by Moura and Shukla (1981) and more recently by Pezzi and Cavalcanti (2001).

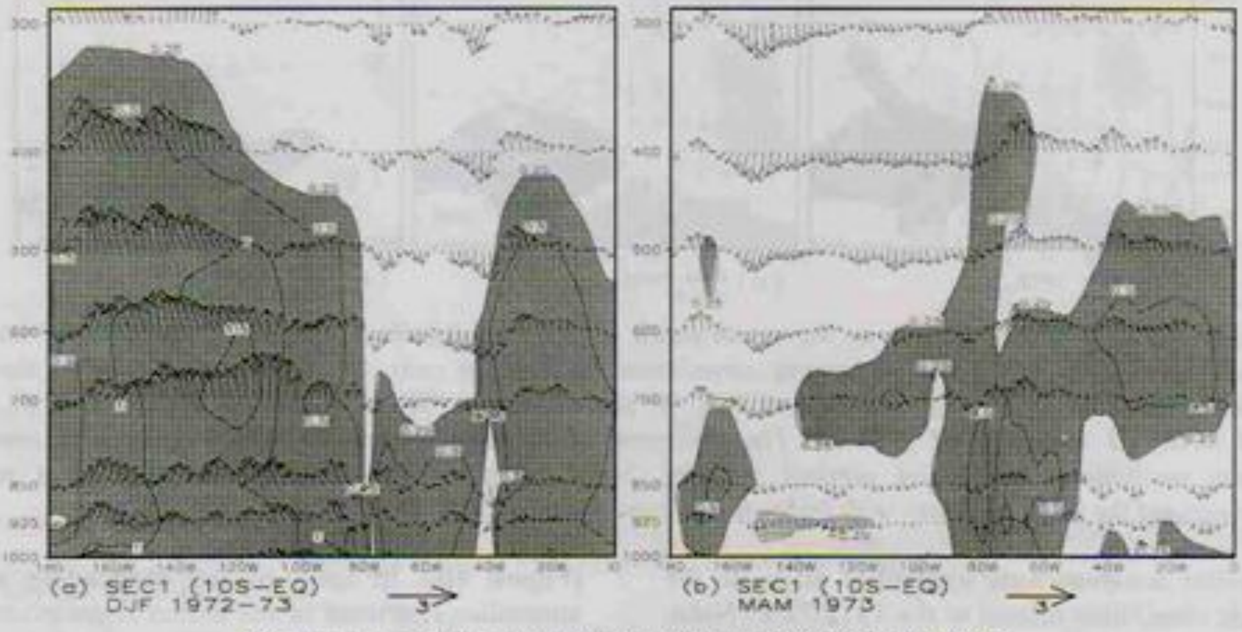

Figure 7: As in Fig.5 but for the DJF and MAM of 1972-73.

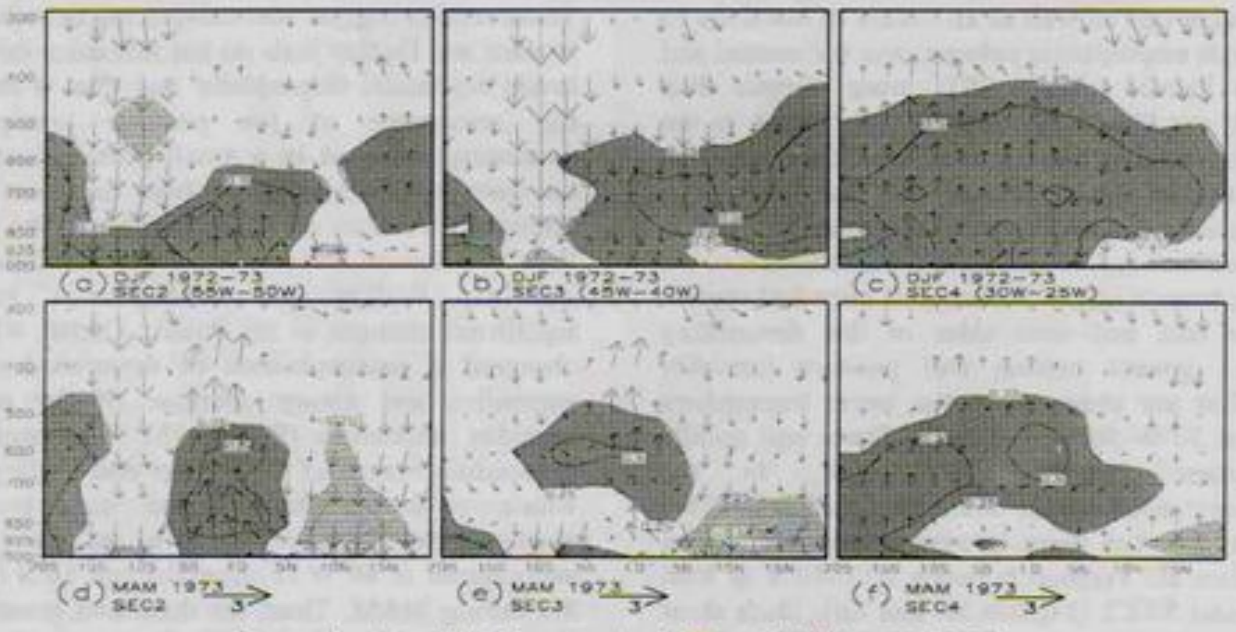

Figure 8: As in Fig.6 but for the DJF and MAM of 1972-73.

The position of the equatorial maximum ascending branch of the Hadley cell observed during the El Niño and La Niña years (Figures 6 and 8) shows the location of the large-scale convective activity linked to the ITCZ. In order to better explain the precipitation deviations observed during the DJF and MAM (Figure 4) and its relationship with the ITCZ position, the horizontal wind and the meridional component of the wind field at 1000 hPa were plotted (Figure 9). The zero wind line from Figure 9 shows the region of the meridional wind convergence, which approximately defines the position of the ITCZ. From the analysis of Figure 9 one can notice an opposite pattern between the two ENSO events. A strong northerly (southerly) wind component over the Northeast Brazil and intertropical Atlantic is observed during DJF and MAM of 1972-73 (1954-55). This feature suggests the positioning of ITCZ to the south (north) of the equator over the equatorial Atlantic and may explain the above (below) normal precipitation noticed during these years (Figure 4). It has been shown (Hastenrath and Heller 1977; Rao et al 1996; Nobre and Shukla 1996) that strong Atlantic trades bring anomalous moisture into the Amazon and Northeast Brazil and they are associated with a southward displaced ITCZ, which is in turn related to an anomalous distribution of Atlantic SST anomalies. In summary, comparing Figures 3, 4 and 9 together with the Walker and Hadley circulation analyses (Figures 5, 6, 7 and 8), it seems that regardless the ENSO event over the Pacific ocean, the Atlantic SST meridional gradient can modulate the precipitation over the eastern Amazon and Northeast Brazil through the modification of the ITCZ position. Thus, some care must be taken when one assumes an abundant or deficient rainy season over these regions only looking at the SSTa over the central and eastern Pacific.

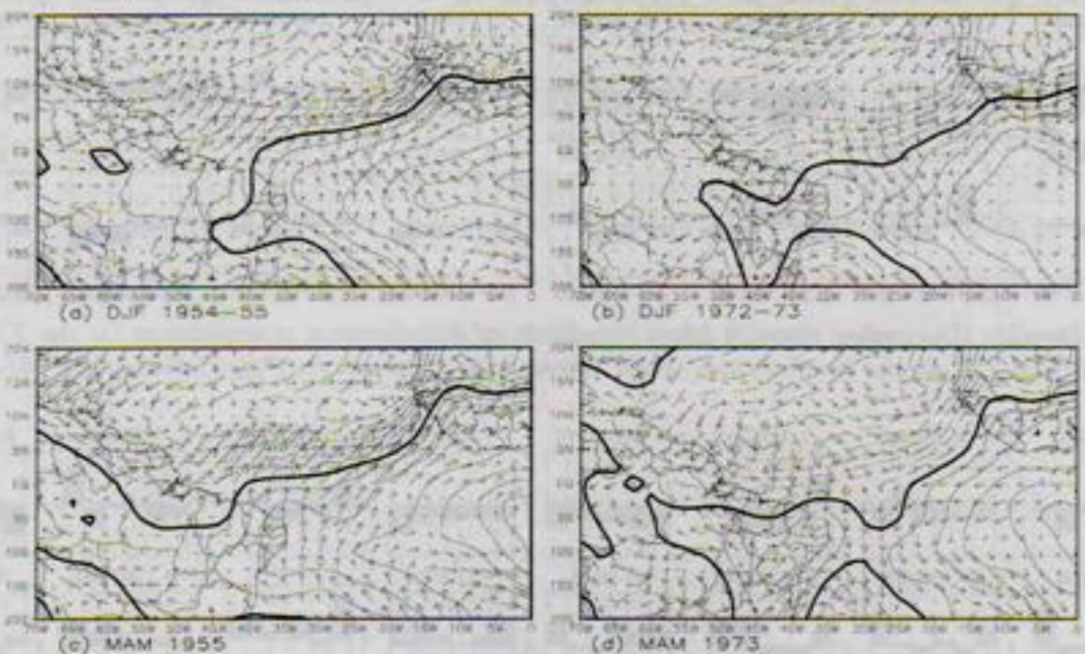

Figure 9: Meridional wind field (contours in m/s) and horizontal wind anomalies (vectors in m/s) at 1000 hPa for the DJF and MAM of 1954/55 La Niña (a and c) and 1972/73 El Niño (b and d) years. The contour intervals are 1 and the dash and solid lines indicate negative and positive values respectively. A thick solid line shows the zero contour.

3.3. Data Analyses from Raingauge Stations

Since the spatial resolution of the precipitation data compiled by Chen et al (2002) can relatively be insufficient to extract more consistent results, we included an analysis of precipitation data in regional scale using the monthly precipitation records for 32 rain gauge stations dispersed around the northeastern South America (Figure 1). Figures 10 and 11 show the standardized deviations (monthly value minus long-term mean, divided by the standard deviation) of precipitation computed for the 32 stations from December to May of the 1954-55 (La Niña) and 1972-73 (El Niño) years, respectively. From the analysis of the individual stations we notice that there is a high variability on the monthly precipitation for both ENSO episodes, with some emphasis over the Northeast Brazil. In general, the rainfall values are consistent with the spatial configuration shown in the Figure 4. During the 1954-55 La Niña event, several stations located in the north of South America (stations number 1 to 9 from Figure 1) presented positive precipitation deviations in most of the months. In the remaining stations, scattered over the east Amazon and Northeast of Brazil (stations number 10 to 32), negative precipitation deviations from December to May are observed. On the other hand, during the 1972-73 El Niño (Figure 11) an inverse pattern was noticed, with precipitation deficit in the stations located to the north of the South American continent (stations number 1 to 9) and precipitation excess in the remaining stations, over northeastern South America.

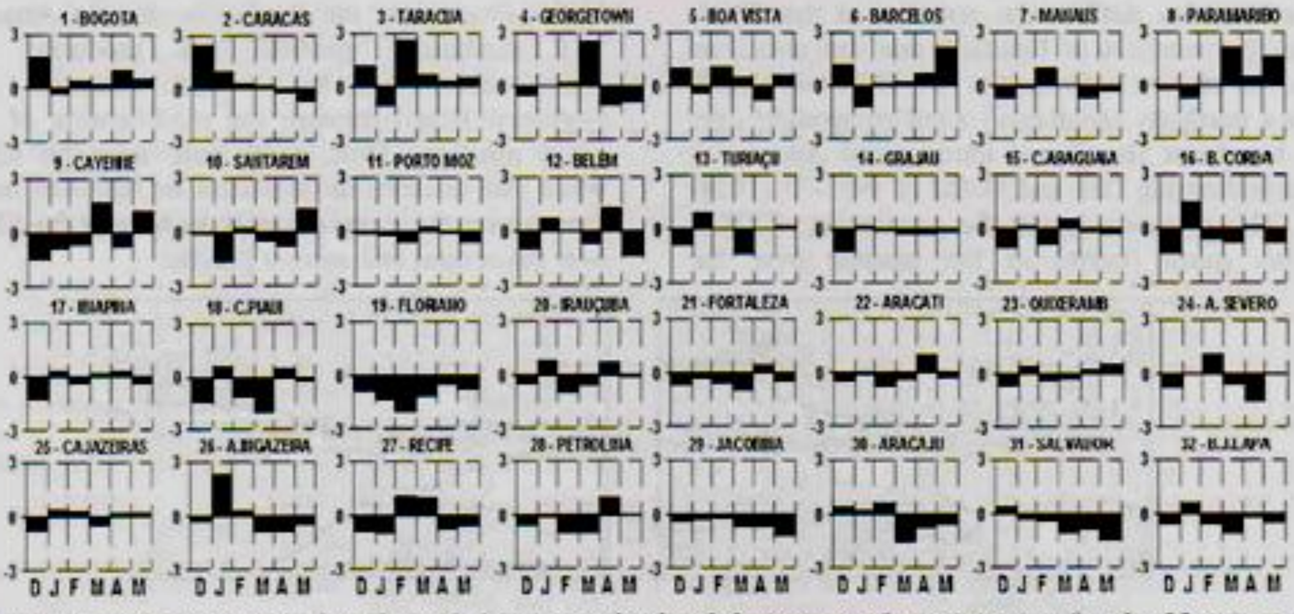

Figure 10: Monthly (December through May) standardized deviations of precipitation for the 32 rain gauge stations distributed along the northeastern South America (as shown in the Fig. 1) during the 1954-55.

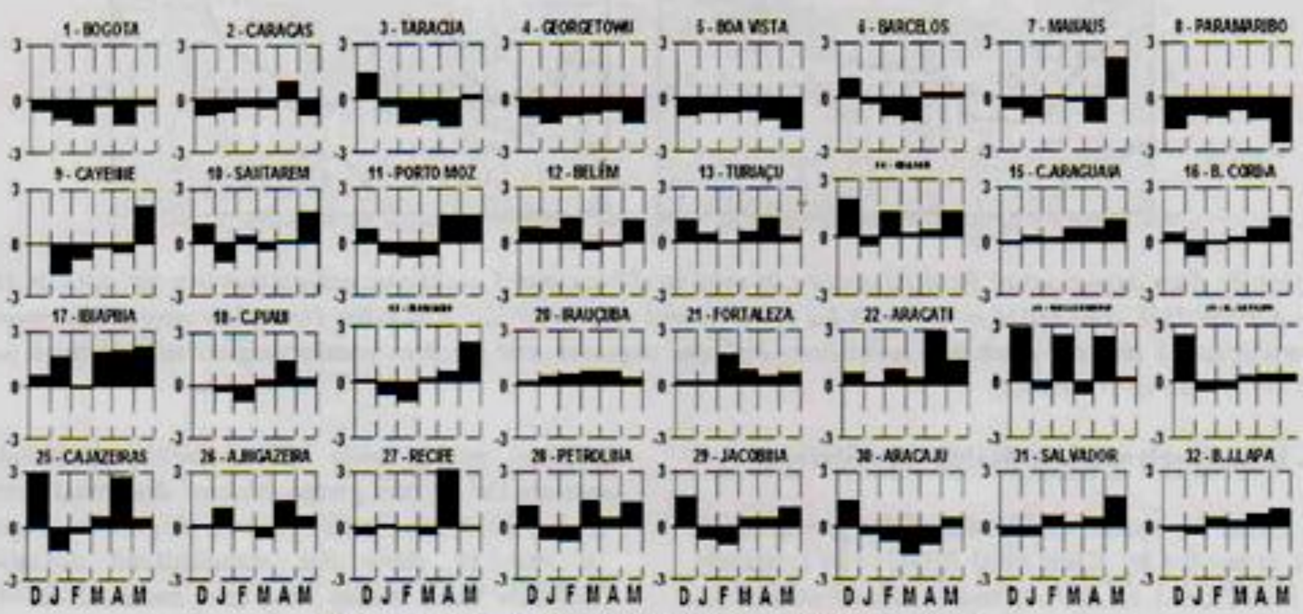

Figure 11: As in Fig.10 but for the 1972-73 period.

4. CONCLUDING REMARKS

This paper shows a diagnostic analysis of the large-scale meteorological characteristics associated with the ENSO events observed in 1954-55 (La Niña) and 1972-73 (El Niño), which were marked by reversed impact on the regional precipitation observed over the northeastern South America.

Analyses based on vertical cross-sections of the atmospheric circulation in altitude revealed dramatic changes in the ascending and descending branches of the Walker and Hadley cells over the tropical Pacific, South America and tropical Atlantic sectors. In the Pacific Ocean, the La Niña stayed well configured during both summer and autumn of 1954-55, however the El Niño presented its mature phase during the summer of 1972-73 and an abrupt decline during the autumn of 1973. On the other hand, in the tropical Atlantic Ocean, a simultaneous anomalous heating (cooling) of the oceanic waters in tropical north basin and anomalous cooling (heating) in tropical south basin generated a thermally direct atmospheric meridional circulation cell with ascending branch to the north (south) of the equator and descending branch to the south (north). Consequently, the ITCZ was anchored to the north (south) of its climatological position, explaining the rainfall deficit (excess) conditions registered over some areas of the northeastern South America, which basically includes the eastern Amazon and Brazilian Northeast regions, during DJF and MAM of 1954-55 (1972-73). Hence, particularly in these years, the large-scale oceanic and atmospheric patterns related to the intertropical Atlantic SST gradient, created dynamic conditions that modulated the positioning of ITCZ in the equatorial Atlantic and regulated the rainfall anomalies observed in the northeastern South America, overcoming the effect of the ENSO mode observed in the tropical Pacific.

The analyses of the two ENSO events presented here, indicated that particularly over the eastern Amazon and most of Northeast Brazil, climate impacts can have a reversed sign when compared to that commonly found in the literature. This result suggests that some care must always be taken before drawing any general conclusion of ENSO impacts. It is clear that for the above-mentioned regions, the Atlantic played a very important role.

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