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Artigo

Upper Tropospheric Cyclonic Vortex and Brazilian Northeast Jet Stream over Alagoas State: Circulation Patterns and Rainfall

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Abstract

Interaction between Brazilian Northeast Jet Stream (BNEJS) and Upper Tropospheric Cyclonic Vortexes (UTCV) isn't still well known, as well as its seasonal variability and relation with rainfall pattern. This study's aim is to determine the air circulation patterns in UTCV events with BNEJS in La Niña and El Niño years and its connections with rainfall in the Alagoas State. These connections were analyzed for 9 years between 1988 and 2000 in El Niño, La Niña and Neutral years. NCEP Reanalysis data, rainfall data from 71 meteorological stations and satellite images were used. Fifty-eight percent of 140 observed UTCVs were associated with BNEJS events located in the Brazilian Northeast and 26%, located over the Alagoas State. Three types of BNEJS patterns, denominated as Meridional (M), Zonal (Z) and Transversal (T), have been identified. The M-type BNEJS was the most frequent in Alagoas State, especially in El Niño years. Z and T-types occurred less frequently and were rarely seen in La Niña years. The results showed that in the M-type BNEJS events in 48% of days were not registered precipitation, while Z and T events recorded rainfall in almost 96% of the days.

Keywords: Brazilian Northeast jet stream, upper tropospheric cyclonic vortexes, ENSO.

Vórtice Ciclônico em Altos Níveis e Corrente de Jato do Nordeste Brasileiro sobre o Estado de Alagoas: Padrões de Circulação e Precipitação

Resumo

A interação entre Corrente de Jato no Nordeste Brasileiro (CJNEB) e o Vórtice Ciclônico em Altos Níveis (VCAN) ainda não é bem estudada, assim como sua variabilidade interanual e sua relação com a precipitação. O objetivo deste estudo é determinar os padrões de circulação em eventos de VCAN com CJNEB nos anos de La Niña e El Niño, e também a conexão deles com as precipitações no Estado de Alagoas. Essas conexões foram analisadas durante 9 anos (1988-2000), divididos em períodos de El Niño, La Niña e Neutro. Neste período foram observados 140 VCANs, os quais 58% estavam associados a eventos de CJNEB e 26% localizados sobre o estado de Alagoas. Foram identificados 3 padrões de ocorrência de CJNEB, denominadas de Meridional (M), Zonal (Z) e Transversal (T). No estado de Alagoas, a CJNEB M é a mais frequente, principalmente em anos de El Niño. CJNEBs dos tipos Z e T ocorrem com menos frequência e raramente são observadas em anos de La Niña. Os resultados mostraram que nos eventos de CJNEB M, em 48% dos dias não se registraram precipitação, enquanto que nos eventos de CJNEB Z e T foram registrados dados precipitação em quase 96% dos dias.

Palavras-chave: corrente de jato do Nordeste Brasileiro, vórtices ciclônicos em altos níveis, ENSO.

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1. Introduction

Weather conditions in the Brazilian Northeast (BNE) are influenced by tropical and subtropical meteorological systems such as Cold Fronts, Intertropical Convergence Zone (ITCZ; see, e.g., Hastenrath and Lamb, 1978), Upper-Tropospheric Cyclonic Vortex (UTCV; Kousky and Gan, 1981), Middle Tropospheric Cyclonic Vortex (MTCV; Fedorova *et al*., 2016), Upper-Tropospheric Troughs (UTT; Newell *et al*., 1972), Instability Lines (Kousky 1980), Easterly Waves (Gomes *et al*., 2019) and others. The region is influenced by El Niño Southern Oscillation ENSO episodes, with dry conditions in El Niño and wet in La Niña (Kousky *et al*., 1984; Ropelewski and Halpert, 1987; Uvo *et al*., 1998; Cavalcanti, 2012).

UTCVs are important synoptic scale systems in this region. They are formed in the high troposphere, and have a cold center with sinking, and lifting air on the periphery (Gan, 1982; Gan and Kousky, 1986; Kousky and Gan, 1981; Rao and Bonatti, 1987; Kayano *et al*., 1997; Mishra *et al*., 2007). Strong convection with rainfall was registered in the UTCV periphery and cloudless weather under the center. This means that UTCV is very important for a rainfall forecast.

Ramirez (1996) showed that greatest UTCV frequency occurs in the austral summer period, with the maximum frequency in January. A relation between UTCV number and variability in extreme ENSO years wasn't clearly found. It was found that UTCVs were observed only at the high levels in La Niña years and were deeper in the El Niño years.

UTCVs were located in the Atlantic Ocean during the rainy season and in the east of the Amazon region during the dry period (Chaves and Cavalcanti, 2001). Silva (2005) showed that the highest frequency of heavy rainfall were associated with the UTCV edge and were located between 1000 and 2000 km off the UTCV center. UTCVs penetrate into Brazil, affecting distribution and intensity of the rainfall, especially in the BNE (Gan and Kousky, 1986).

Upper tropospheric jet stream has an important effect on the physical processes in the lower atmosphere. It represents an important factor in synoptical and climatological time scales. The jet stream modifies the associated divergence field (Ziv and Paldor, 1999), changing vertical drafts intensity in the jet streaks adjacencies and affecting cyclogenesis (Rose *et al*., 2004), conducting the weather patterns (Trenberth, 1991). The existence of strong wind streams between the northeast sector of the Bolivian High (BH) and the UTCV's southwest sector was shown by Ramirez (1996). It was suggested that those streams are associated with the subtropical jet and attributed to the UTCV development. According to Virji (1981) data, south component of the winds between BH and UTT can reach speeds of more than 20 m s^{-1}. Gomes (2003) studied these strong air streams at high levels near the BNE, which was named the Brazilian Northeast Jet Stream (BNEJS). These jet streams were seen to be associated with UTCV in some cases. The BNEJS, with a minimum speed limit of 20 m s^{-1}, occurred very often (it was detected almost every day) (Fedorova *et al*., 2018a). The same paper shows that directions of the BNEJS were identified to be more often from the northwest and the southwest and were rarely found occurring from the north. Campos and Fedorova (2006) also observed connections between BNEJS and other synoptic systems, such as UTCVs in both the Southern and Northern hemispheres, as well as a modification on the vertical structure of UTCV due to transversal circulations produced by BNEJS. During months from December to February (dry period) in the coastal region, the most frequent cases of BNEJSs are those located between the UTCV and the Bolivian High (Fedorova *et al*., 2018b). UTCV and BNEJS, acting separately, are responsible for most of the intense rainfall (Pontes da Silva *et al*., 2011) and days with thunderstorms (Brito *et al*., 2011) in the Alagoas State.

Interactions between strong wind streams with BNEJS and UTCV isn't still well known, as well as its seasonal variability and relation with the BNEJS rainfall pattern. This study's aim is to determine the air circulation patterns in UTCV events with the BNEJS in La Niña and El Niño years and connections with rainfall in the Alagoas State.

2. Data Source and Methodology

2.1. Data source and study periods

The UTCV and BNEJS events were analyzed using reanalysis data (daily average) from the National Center for Environmental Prediction - National Center for Atmospheric Research (NCEP-NCAR). This information was available in the grid points with 2.5° × 2.5° of latitudinal and longitudinal spacing (Kalnay, 1996). Zonal (u), meridional (v) and vertical (ω) speed components of wind at the standard isobaric levels, derived variables (stream lines and vertical motion) and outgoing longwave radiation data (OLR) were used. The package "Grid Analysis and Display System" (GRADS) supplied by the Center for Ocean-Land-Atmosphere (COLA), was used for data visualization and manipulation.

The study period (Table 1) was divided by El Niño, La Niña and neutral episodes, according to the Oceanic Niño Index (ONI).

The most intense events of ENSO between 1988 and 2000 were selected. The El Niño event of 1997/98 and the La Niña event of 1998/99, which were the strongest episodes of the century, caused great influence in the circulation and rainfall patterns over South America (Wang and Weisberg, 2000). Neutral years close to selected years

Table 1 - Study periods according to the ENSO episodes.

La Niña		El Niño		Neutral
Years	Intensity	Years	Intensity	Years
1988-89	Strong	1991-92	Strong	1989-90
1998-99	Strong	1994-95	Moderate	1990-91
1999-00	Strong	1997-98	Very Strong	1996-97

*The threshold is further broken down into Weak (with a 0.5° to 0.9° SST anomaly), Moderate (1.0° to 1.4°), Strong (1.5° to 1.9°) and Very Strong (≥ 2.0°) events.

were chosen according to the greater availability of rainfall data in the Alagoas State. The highest frequency of the UTCV-BNEJS events was observed between November and March (Repinaldo, 2010), therefore this period has been analyzed. Also, the same months of El Niño, La Niña and neutral years were chosen to avoid the effects of seasonal changes in circulation.

2.2. UTCV identification and analysis

UTCVs identification was elaborated using maps of wind speed, streamlines and relative vorticity at 200 hPa over the BNE region and the adjacent Atlantic Ocean, (Fig. 1, domain A). All events with cyclonic circulation and minimum vorticity were identified as UTCV in the domain A. The method of the Field Analysis (FA) was selected because it can identify a larger amount of UTCVs (Coutinho *et al*., 2010). Each UTCV was analyzed from the first cyclonic circulation confirmation up to its dissipation. The cloudiness associated with UTCV were confirmed by the analysis of the infrared (IR) and water vapor (WV) channels, using METEOSAT data.

2.3. BNEJS identification and analysis

The BNEJS was defined as a jet current between 20-50° W and 0-20° S with a maximum wind speed in its core above 20 m s^{-1} (Fedorova *et al*., 2018a). Therefore, this value (20 m s^{-1}) was used as a lower limit for the maximum wind speed in its core at 200 hPa level. BNEJS frequencies with a maximum wind speed above 20 m s^{-1} associated with UTCV were analysed over the BNE region, as well as the events that affected the Alagoas State (Fig. 1, domain B). If more than one jet stream was detected in the study region, it was calculated as one day with a jet steam. The following three BNEJS types were observed: Meridional (M), Zonal (Z) and Transversal (T). Theses types were identified according to Repinaldo (2010) and Costa *et al*. (2013). An example of three BNEJS types is presented in Fig. 2.

2.4. Rainfall data

Daily precipitation data from 71 meteorological stations was supplied by the Secretary of the Environment and Water Resources of Alagoas (Secretaria de Estado do Meio Ambiente e dos Recursos Hídricos-SEMARH) through the Department of Meteorology (Diretoria de Meteorologia-DMET). Environmental regions of the Alagoas State are presented in Fig. 1. Because of the lack of some data, the number of meteorological stations in each environmental region was different during ENSO periods

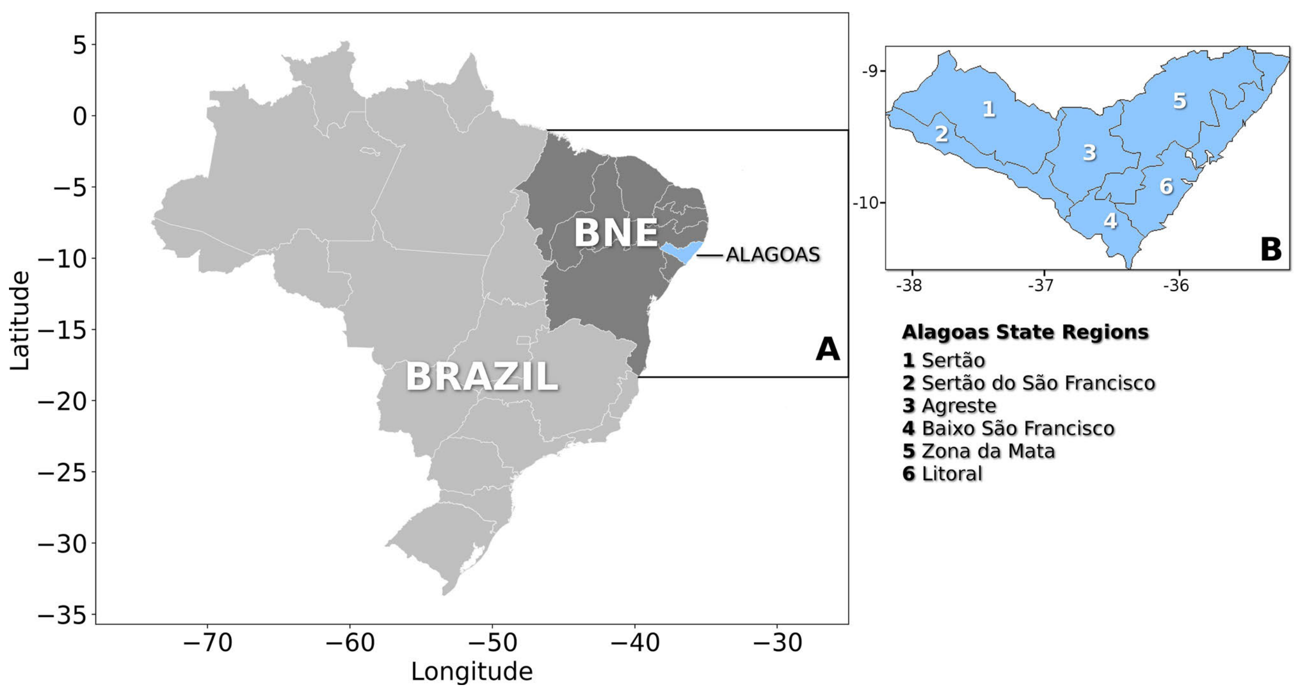

Figure 1 - Regions locations: (A) BNE and (B) environmental regions distribution in Alagoas State.

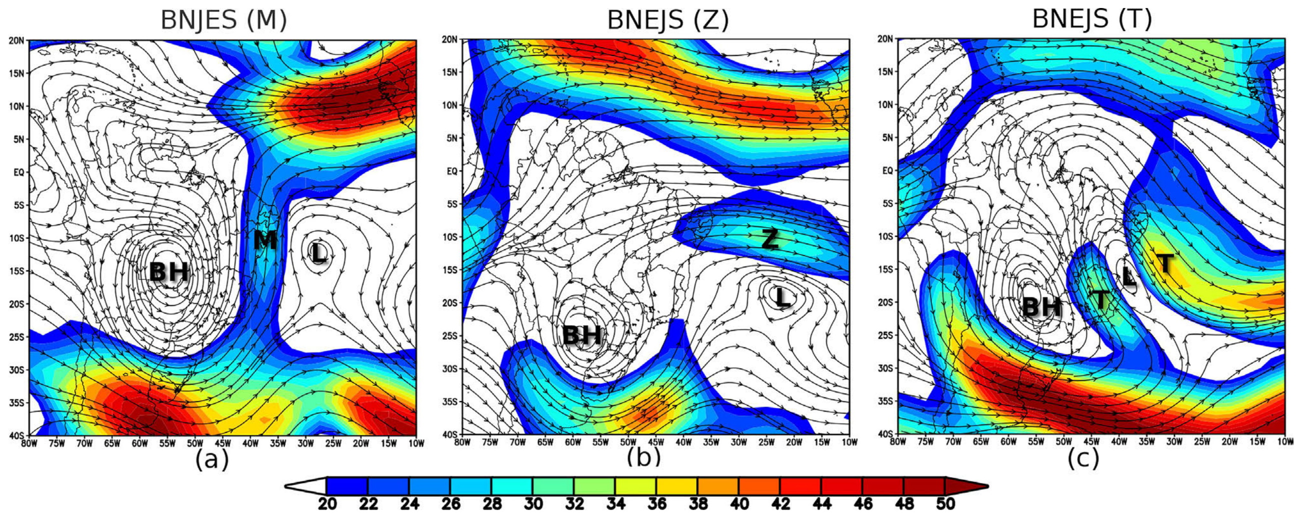

Figure 2 - Stream lines and wind speed (m s^{-1}) at 200 hPa level for three types of UTCV-BNEJS events: (a) Meridional (M) (01/02/1995); (b) Zonal (Z) (09/02/1990) and (c) Transversal (T) (10/11/1996). Positions of the Bolivian High (BH), UTCV (L) and three types of BNEJS (M, Z, T) are shown in the figures.

(Table 2). Precipitation above 0.1 mm day^{-1} was used for rainfall classification.

Distribution of the precipitation frequency and relative accumulated frequency for the UTCV-BNEJS events in the Alagoas State are shown in Fig. 3. The highest frequency (55 records) was registered during low precipitation (less than 1 mm day^{-1}). Precipitation between 0.1 and 6.1 mm day^{-1} was observed in 66% of rainfall records. Precipitation above 7 mm day^{-1} occurred in 30% of records.

Considering all precipitation data during UTCV-BNEJS events in Alagoas State, three categories were defined to classify the intensity of rainfall (Fig. 3b): Category I (0%-66%): $0.1 \geq P \leq 6.1$ mm day^{-1}; Category II (66%-95%): $6.1 > P \leq 28$ mm day^{-1}; Category III (95%-100%): $P > 28$ mm day^{-1}.

3. Results and Discussion

3.1. UTCV and BNEJS occurrence during El Niño and La Niña years

It is well known that ENSO causes several changes in the atmospheric general circulation (Grimm *et al.*, 2000; Ambrizzi *et al.*, 2004). These changes are mainly associated with the weakening, intensifying and/or displacement of large-scale atmospheric circulation in the meridional and zonal directions, especially related to the Hadley and Walker circulations (Kidson, 1975; Kousky *et al.*, 1984). In spite of these changes, UTCV occurrence did not show a significant variability in extreme ENSO years (Table 3). A slight increase (+1.4%) in number of cases in El Niño years and a decrease (-6.4%) in La Niña years have been observed, both in relation to neutral years. The average duration of UTCV events was 6 days. Ramirez (1996) obtained and described similar results. Number of UTCV-BNEJS events in the Region A increases during El Niño period (+12.2%) and decreases (-7.3%) during La Niña period. This decrease is similar to the decrease in the occurrence of UTCV events. There is also an increase (decrease) in the number of cases in El Niño (La Niña) years in Alagoas State, which is more significant in La Niña Years (-16.1%).

It is important to emphasize that 70.6% of UTCV events formed BNEJS at some point in their life cycle, in El Niño years. The values fall to 50 and 53% in La Niña and Neutral years respectively (Table 3).

Results from the maximum wind speed study in the BNEJS are presented in Table 4. Wind speed are more intense during El Niño and Neutral years, reaching 40 m s^{-1}. During La Niña years the wind did not exceed 32 m s^{-1}. The wind reached 28 m s^{-1} in 25% of cases during El Niño years and only in 14.3% in La Niña years. These results are in accordance with the Subtropical Jet Stream (SJS) intensity in South America for El Niño years (Arkin, 1982;

Table 2 - Meteorological stations number in each environmental region of Alagoas State.

	Backlands	São Francisco Backlands	Agreste	Low São Francisco	Forest Zone	Coast	Total
El Niño	11	5	7	4	13	18	58
La Niña	10	5	9	4	16	19	63
Neutral	9	4	8	5	14	11	51

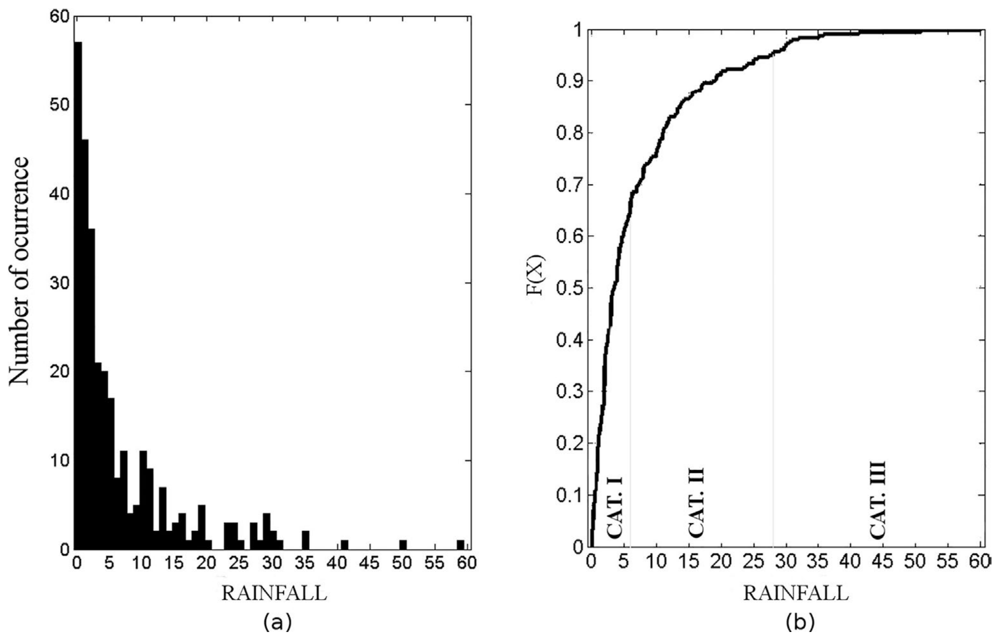

Figure 3 - (a) Precipitation frequency (mm day^{-1}) and (b) relative accumulated frequency for all meteorological stations in UTCV-BNEJS events that occurred in Alagoas State.

Table 3 - UTCV occurrence of cases in the Region A and B (Alagoas State). Numbers in parenthesis corresponds to occurrences (days) in Alagoas State.

	UTCV	UTCV-BNEJS	
		Region A	Region B
El Niño	51(307)	36 (133)	15 (35)
La Niña	40 (255)	20 (56)	8 (14)
Neutral	49 (294)	26 (93)	14 (28)
Total	140 (856)	82 (282)	37(77)

Table 4 - Occurrence in number of days of the maximum wind speed (m s^{-1}) in the UTCV-BNEJS Jet Stream in the Region A.

	BNEJS jet streak (m s $^{-1}$)				
	24	28	32	36	40
El Niño	39	60	31	2	1
La Niña	29	19	8	0	0
Neutral	37	39	8	8	1
Total	105	118	47	10	2

Kousky *et al.*, 1984; Cruz, 1998) due to its possible connection with BNEJS.

The UTCV-BNEJS events have been divided into three groups, based on BNEJS's jet stream direction (Fig. 2). T-type BNEJS was observed more frequently (138 days) than M and Z-types BNEJS (93 and 58 days, respectively) (Table 5). However, M-type BNEJS was the most frequent (43 days) in the Alagoas State.

T-type BNEJS predominated during El Niño and La Niña years (Table 5). Z-type BNEJS was registered mainly

Table 5 - Occurrence in days of the UTCV-BNEJS types. Parenthesis corresponds to occurrences (number of days) in Alagoas State.

	BNEJS type		
	Meridional	Zonal	Transversal
El Niño	37 (21)	42 (10)	54 (4)
La Niña	16 (13)	2 (0)	38 (1)
Neutral	40 (9)	14 (7)	39 (12)
Total	93 (43)	58 (17)	131 (17)

during the El Niño years, while M-type BNEJS was typical in El Niño and Neutral years. In the Alagoas State, a greater frequency of M-type BNEJS was observed during El Niño period, while T-type BNEJS were rarely observed in La Niña years. Z-type BNEJS was not observed during this period in the Alagoas State.

3.2. UTCV-BNEJS circulation patterns

Each type of upper level (200 hPa) UTCV-BNEJS circulation patterns in the Alagoas State will be discussed below. Figs. 4, 5 and 6 have been elaborated for the M, Z and T-types BNEJS and present a different circulation pattern for each type.

3.2.1. Meridional BNEJS circulation pattern

The M BNEJS (Fig. 4) located near the BNE eastern coast, presented a medium intensity (26 m s^{-1}) and was observed in 55.8% of UTCV-BNEJS days in Alagoas State. M-type BNEJS was more frequent in El Niño years (48.8% of all days with M-type UTCV-BNEJS).

This jet stream was located between two classical circulation systems during the summer: Bolivian High (BH) and UTCV (Fig. 4a). BH center was observed at 14° S and 61° W in these events, to the north of its climatological position for summer (Virji, 1981). UTCV is the classical vortex type described by Kousky and Gan (1981). In this pattern the Subtropical Jet Stream of the Southern Hemisphere (SJSSH) is zonal and weak above the continent (the maximum speed core is centered between 35° S and 45° S). The Subtropical Jet Stream of the Northern Hemisphere (SJSNH) is located to the north of the UTCV and the maximum speed core is centered at 15° N. This jet stream was tied up to the SJSSH through the Southern BNEJS in 28% of cases during El Niño years and 11% for Neutral years (not shown). This connection was not observed for La Niña years.

Cross-section of the wind (u, ω) and the vertical cyclonic relative vorticity passing through the M-type BNEJS and on the UTCV's axis (10° S) can be seen in Fig. 4b. The southern horizontal wind components intensified the M-type BNEJS. This process was associated with the UTCV circulation (negative values of vertical relative vorticity). This circulation extended vertically from a level of 500 hPa to a level above 100 hPa. The jet stream of M-type BNEJS was located at the same level as the core of a minimum relative vorticity (-4×10^{-5} s^{-1}) of UTCV.

The M BNEJS-UTCV cloud pattern is also shown using the outgoing longwave radiation data (OLR) (Fig. 4c). In the northern sector of UTCV, low OLR values (< 240 W m^{-2}) were associated with a convective ITCZ's activity and ageostrophic circulation at the SJSNH's entrance. Cloud pattern associated with UTCV was formed at the periphery from the center. Cloudiness was formed in the east side of the jet stream in M-type UTCV-BNEJS events. This pattern is consistent with the moist air advected by the South Atlantic Anticyclone (SAA) toward the BNE and lifting at the periphery of UTCV (Fig. 4b). In the south of UTCV, the presence of low OLR values oriented in the SE-NW direction and extending to the Amazon region, is the characteristic of South Atlantic Convergence Zone events (SACZ; Carvalho *et al*., 2002).

UTCV associated with M-type BNEJS always has a maximum cyclonic relative vorticity of ≤ -5 x 10-5 s^{-1} in its center, and in 40.4 % of the cases, those values are lower than -6×10^{-5} s^{-1} (not shown).

3.2.2. Zonal BNEJS circulation pattern

Z-type BNEJS (Fig. 5) is detected in 13% of the UTCV-BNEJS days, with a medium speed of 29 m s^{-1}. These BNEJSs were registered in El Niño and Neutral years (in 58.8% and 41.2% of days, respectively) and were not observed in La Niña years.

A typical Z-type BNEJS location was observed above the BNE northern region and adjacent to the Atlantic Ocean (Fig. 5a). It is important to note that this location is very steady. The BH was centered at 10° S, 64° W and its ridge reached the Atlantic Ocean between 25° S and 30° S. In some cases without BH, only a zonal flow bifurcation was observed near the South American west coast. These situations were associated with more intense Z-type BNEJS. UTCV location was situated more south than UTCVs associated with M-type BNEJS. SJSSH appears south of the BH ridge. This ridge is more intense than in the M-type BNEJS events.

Cross-section of the wind (v, ω) and the vertical cyclonic relative vorticity passing through the Z-type BNEJS and on the axis of the UTCV (38° W) are shown in Fig. 5b. The vertical extent of westerly winds was similar to M jet events and its jet stream was slightly more exten-

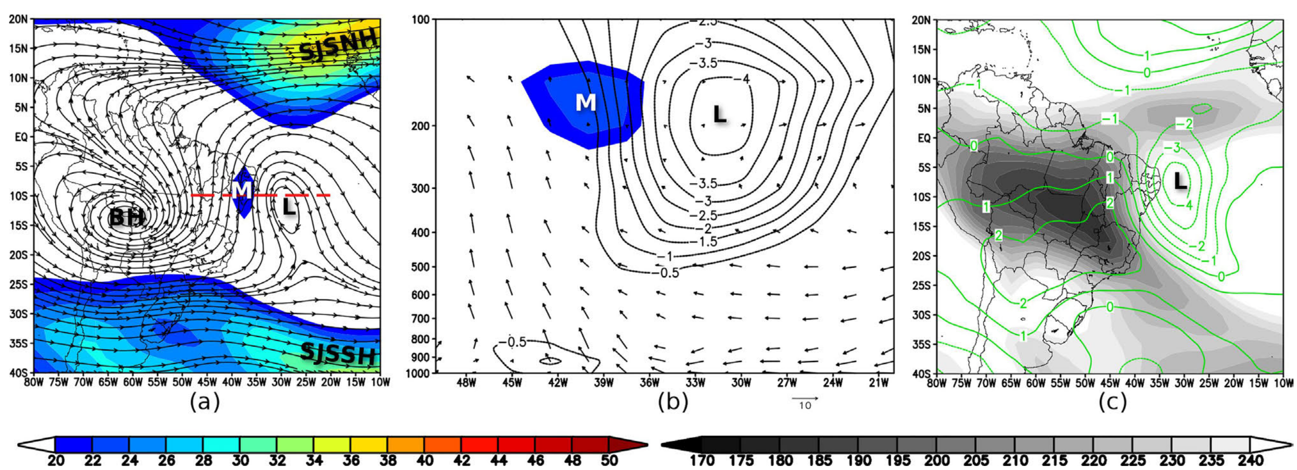

Figure 4 - Meridional BNEJS circulation pattern: (a) streamlines and wind speed (m s^{-1}) at the 200 hPa level; (b) vertical cross-section [u,ω] (vectors), wind speed [u,v] (shaded, m s^{-1}) and vertical cyclonic relative vorticity (contours, $x10^{-5}$ s^{-1}), along 10° S; (c) outgoing longwave radiation (OLR, W m^{-2}) and vertical relative vorticity (contours, $x10^{-5}$ s^{-1}). The vertical cross-section is indicated by the dashed red line in the figure (a).

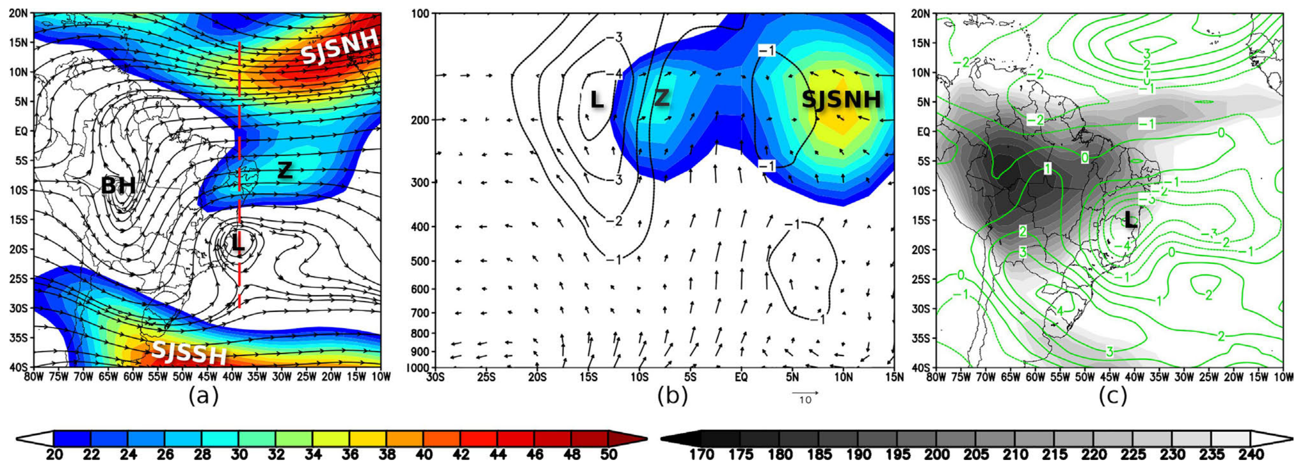

Figure 5 - Zonal BNEJS circulation pattern: (a) streamlines and wind speed (m s^{-1}) at the 200 hPa level; (b) vertical cross-section [v,ω] (vectors), wind speed [u,v] (shaded, m s^{-1}) and vertical cyclonic relative vorticity (contours, x10^{-5} s^{-1}), along 38° W; (c) outgoing longwave radiation (OLR, W m^{-2}) and vertical relative vorticity (contours, x10^{-5} s^{-1}). The vertical cross-section is indicated by the dashed red line in the figure (a).

ded (150-300 hPa). SJSNHs were located at 10° N and were coupled to the Z-type BNEJS in 88% of the days.

Cloud pattern showed that low OLR values associated with Z-type UTCV-BNEJS events were located in the northern sector of the cyclonic vortex corresponding to the jet entrance region (Fig. 5c). This pattern is consistent with the moist air caused by offshore winds and with the lifting on the periphery of UTCV (Fig. 5b). In this jet type cloud pattern associated with SACZ events was not observed.

The most frequent relative vorticity in the UTCV center associated with Z-type BNEJS reached -6 x 10^{-5} s^{-1}. Vorticities of less than -8 x 10^{-5} s^{-1} were not observed (not shown).

3.2.3. Transversal BNEJS circulation pattern

T-type BNEJSs were associated with UTCV in 22% of days; 70.6% of these cases occurred during Neutral years. This pattern showed that two streams associated with the same UTCV can be observed (Fig. 6a): one up to the southwest from the UTCV center and another to the northeast. The last one was located on the eastern BNE coast and was the only one that has been observed over the Alagoas State. In these events, the UTCV centers were located near the coast or above BNE region and had a trough stretched to the northwest. BHs were located above western Bolivia and their ridges were situated to the northwest, up to the Atlantic Ocean. Air current was diffluent in the Amazon region.

Wind speed in the jet stream of the T-type BNEJS presented an average intensity of 31 m s^{-1}. These BNEJSs were the most intense compared to Z and M-types BNEJSs because they were associated with the most intense UTCVs (relative vorticity up to -14 x 10^{-5} s^{-1}). Compared to the other patterns, SJSSHs were stronger on the continent and its maximum speed in the core reached 48 m s^{-1}. The SJSNH position was more to the north compared to the Z and M-types BNEJSs. Sometimes it was observed that a branch of SJSNH enters the Southern Hemisphere and is coupled to T-type BNEJS. It is observed in the cross-section (Fig. 6b) that T-type BNEJS has a thickness similar to the jet type T. Its level and thickness are the same as the center of the minimum negative relative vorticity associated with UTCV. Lifting was not observed below the T-type UTCV-BNEJS (Fig. 6b). Region of lifting was located on the outside periphery and in the jet entrance region, agreeing with the cloud pattern shown in Fig. 6c.

3.3. Precipitation in the Alagoas State during UTCV-BNEJS events

The occurrence of UTCV-BNEJS cases was observed in 26% of all UTCV cases. Forty-five percent of the UTCV-BNEJS cases were found in the Region A. This corresponds to a frequency of 16% days/year for the period November-March. Since UTCV events are one of the main precipitating systems during the dry period in this area, it is very important to know their frequency to improve the weather forecast.

Table 6 shows the occurrence (number of days) of precipitation during UTCV-BNEJS events, where there is a variability in the amount of rainfall between the different BNEJS types. M-type BNEJS shows the lowest occurrence of precipitation, with 48.7% of days without rain record, while events in T-type BNEJS registered rains every day. It is only possible to analyze precipitation during Z-type UTCV-BNEJS events during Neutral years because of the absence of data in El Niño and La Niña years in the archive. For this type of jet, in 7 days of occurrence, there were 6 recorded precipitation.

As shown in the previous section, in Z and T-types BNEJS events the upwind side of the jet stream was

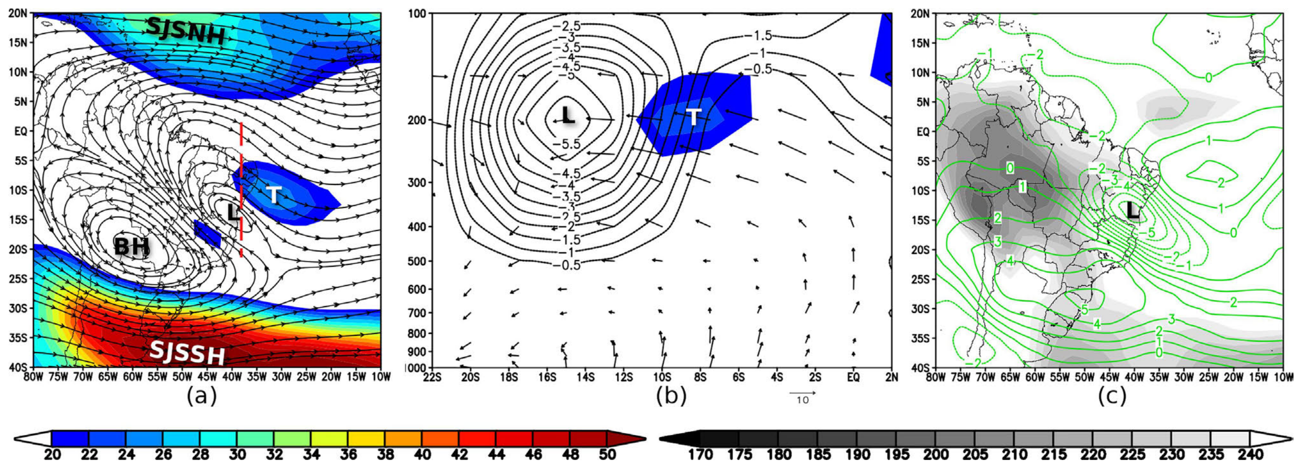

Figure 6 - Transversal BNEJS circulation pattern: (a) streamlines and wind speed (m s^{-1}) at the 200 hPa level; (b) vertical cross-section [v,ω] (vectors), wind speed [u,v] (shaded, m s^{-1}) and vertical cyclonic relative vorticity (contours, x10^{-5} s^{-1}), along 38° W; (c) outgoing longwave radiation (OLR, W m^{-2}) and vertical relative vorticity (contours, x10^{-5} s^{-1}). The vertical cross-section is indicated by the dashed red line in the figure (a).

Table 6 - Precipitation occurrence (number of days) in three categories (I, II e III) during El Niño, La Niña and Neutral years for UTCV-BNEJS types.

	Meridional					Zonal					Transversal				
	d*	NR	I	II	III	d*	NR	I	II	III	d*	NR	I	II	III
El Niño	17	8	9	3	0	0	-	-	-	-	4	0	4	1	0
La Niña	13	5	8	3	1	0	-	-	-	-	1	0	1	0	0
Neutral	9	6	3	2	0	7	1	6	5	2	12	0	11	7	4
Total	39	19	20	8	1	7	1	6	5	2	17	0	16	8	4

d*: days with rainfall data; NR: days without rain; Cat. I: 0.1-6.1 mm day^{-1}; Cat. II: 6.1-28 mm day^{-1}; Cat. III: > 28 mm day^{-1}.

usually located over the Alagoas State, which favors the deep updrafts. Meanwhile in M-type BNEJS events the jet stream was usually located just above the Alagoas State with deep lifting on its periphery, outside the region.

Regarding the rainfall intensity, precipitation was less than 6.1 mm day^{-1} in 67% of UTCV-BNEJS days, while moderate rainfall (6.1-28 mm day^{-1}) occurred in 1/3 of the days. Rainfall exceeding 28 mm day^{-1} was more frequent in Z and T-types BNEJSs events (28 and 23.5% of days, respectively), and all cases were observed during Neutral years.

4. Conclusions

One hundred and forty UTCV events for 9 years were analyzed in El Niño, La Niña and Neutral years. A little more than half of the UTCV events were associated with BNEJS. These jet streams were located near the Alagoas State in 26% of cases. Three patterns of atmosphere circulation in BNE have been identified, in accordance with BNEJS positions. M-type BNEJS was the most common jet stream observed over the Alagoas State and was most frequent in El Niño years. These streams were formed between BH (west) and UTCV (east). These cases were not linked to important rainfall events because the lifting moisture region associated with this pattern was located on the jet stream occidental periphery. Z-type BNEJS were observed only in El Niño and Neutral years in Alagoas State. This jet stream was located to the north of UTCV, which in turn was usually located over the continent. A striking feature of this pattern was the frequent coupling of BNEJS with SJSNH. Due to the location of this jet stream in relation to the Alagoas State, precipitation was observed in 85.7% of BNEJS days. T-type BNEJS was the most intensive jet stream over the Alagoas State. It was more frequent in Neutral years and rarely observed in La Niña years. In this pattern, the UTCV axis tilted west and approached the center of BH. During the T-type BNEJS events, the jet stream entry region was located over the Alagoas State and precipitation was recorded every day, including the highest rainfall frequency, greater than 28 mm day^{-1}, that occurred in Neutral years.

The results of this study show the relationship between upper level cyclonic vortex and jet stream direction and its interannual variability as well as the occurrence of rainfall associated with these synoptic systems. This paper is important for short-term weather forecasts because the results show the connection of the jet streams during El Niño, La Niña and Neutral years with precipitation. This knowledge can help in short-term adverse phenomena forecasts.

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Internet Resources

ONI Oceanic Niño Index https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php.