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SPATIAL DISTRIBUTION OF THE CYCLONIC VORTICITY IN THE NORTHEAST OF BRAZIL AND ADJOINING OCEAN AND ITS RELATION WITH THE ENSO

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ABSTRACT

The upper level cyclonic vortex (ULCV) is one of the main systems that produce alterations in the weather of Northeast Brazil (NEB). The intense trough of upper levels (TUL) over NEB has the similar behavior as the ULCV, presenting cloud in the periphery and absence of cloud in the center. However, the streamlines; do not appear “closed”. The objective of this work is to study the spatial distribution of cyclonic vorticity associated with the ULCV/TUL and its relation with ENSO. Maps of spatial distribution of the frequency of occurrence of relative vorticity were constructed. The days with $\zeta < \zeta_c$ where $\zeta_c = - 2.5 \times 10^{-5}\ s^{-1}$ were computed in each grid point, this value is called cyclone occurrence density. Three subregions: Northwest of the NEB, central Bahia and the semi-arid were selectioned. Two cases of ULCV were selected, the first one in an El Niño year and the second in La Niña year, to compare the vorticity frequency and intensity over the subregions. The results show a high density of cyclonic events over the NEB, except in the subregion of northwest. In the summer of El Niño (1997-1998) a higher density of cyclonic events was observed in the semiarid subregion of NEB, reaching approximately 50 days. In the neutral summer (2000-2001) the central Bahia has 45 days with cyclonic vorticity. On the other hand, in the summer 1995-1996 (La Niña) had a decrease in the number of day with cyclonic vorticity in the domain considered. A displacement of the higher density (~ 30 days) of cyclonic vorticity into the Atlantic Ocean was observed. In this year of La Niña, the three subregions practically did not suffer influences of subsidence centers of ULCV. The case studies showed that as much as in the years of El Niño as in years of La Niña intense ULCV that are capable of inhibiting the rains through subsidence centers can occur.

1. INTRODUCTION

The spatial distribution of the cyclonic vorticity over the NEB and the adjoining ocean is associated with the presence of the trough of upper levels (TUL) or the upper level cyclonic vortice (ULCV). The ULCV is a low-pressure system formed in the upper troposphere and whose closed cyclonic circulation has a center colder. Southern Hemisphere summer circulation in the upper troposphere over South America is characterized by the presence of a quasi-stationary high over Bolivia (HB) and the TUL/ULCV over Northeast Brazil.

Specifically, the ULCV is one of the main systems responsible for the presence or absence of rains over NEB. For this reason, the mechanisms of formation of the ULCV have been studied. Kousky and Gan (1981) proposed that the equatoward-moving cold fronts over South America cause the amplification of the upper level downstream ridge southeast of the HB, and thus are indirectly responsible for ULCV formation. Another mechanism for the formation have been observed, such as, their relation with an upper circulation anticyclone over southwestern. Apparently, this upper circulation anticyclone is related to the South Atlantic Convergence Zone - SACZ (Ramírez et al., 1996, 1999). On the other hand, Paixão (1999) noted that the influence of the African circulation may also play an important role in the formation of ULCV. The numerical simulation studies of Figueroa (1997) indicated that a main factor for the formation of the ULCV is the heat source at low levels near of the coast of the states of Espirito Santo and Bahia.

Regarding the modifications of the weather over NEB, Chaves and Cavalcanti (2001) and Silva (2005) found that the rainy and dry periods are associated with the position of the ULCV. In the rainy period the cyclonic vorticity is positioned in the Atlantic Ocean, while, in the dry period the cyclonic vorticity is positioned to east of the Amazon (Chaves and Cavalcanti, 2001). However, Silva (2005) indicated that the areas that include the central Bahia and the semiarid of the NEB are the most affected by the subsidence center of the ULCV.

The relationship between the ULCV and the El Niño-Southern Oscillation (ENSO) has been less analyzed. Ramírez (1996) observed that in the summers of El Niño (1982-1983; 1986-1987) the ULCV are more intense and extend from 200 hPa to 500 hPa. However, in the events of La Niña (1984-1985; 1988-1989) ULCV were confined to the high levels (200-300 hPa). On the other hand, several investigations have been made to study the relationship between NEB rainfall distribution and

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the ENSO cycles. NEB experiences severe droughts during intense El Niño events (Rao and Hada 1990; Ropelewski and Halpert, 1989; Kayano et al., 1998). Bravo et al. (1997) noted that rainfall over the northen sector of the NEB was around or above climatology in years with predominance of negative anomalies of SST in the basin of the Equatorial Pacific Ocean, when the event La Niña is present. Rao and Hada, (1990) found correlation of negative anomalies between El Niño and the rains in the NEB. However, the relationship between the rainfall associated ULCV over NEB and the ENSO has been less exploited. This study focuses the impacts of ULCV and ENSO on NEB rainfall.

This work intends to explore that subject focusing through case studies, and its role of inhibition of the rains through their subsidence centers during different phases of ENSO.

2. Data and methodology

Daily 100-300 hPa zonal (u) and meridional (v) wind component obtained from the National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP–NCAR) reanalysis for the summer period 1994-2001 were used in the study (Kalnay et al., 1996). These data have a spatial resolution of 2.5° x 2.5° (latitude and longitude).

To confirm the presence and position of the ULCVs, the cloud coverage associated with the cyclonic systems is verified in the IR cloud imagery from the METEOSAT-3 and METEOSAT-5 and GOES-8 at 00 UTC. The cloud imagery is available from http://www.cptec.inpe.br.

The El Niño years and the opposite phase (La Niña) are identified from the Southern Oscillation Index (SOI) available from the National Oceanic and Atmospheric Administration (NOAA). Daily rainfall data from rain gauge stations for the period of study were obtained from the National Agency of the Waters (ANA).

The relative vorticity, $\zeta = (\partial v/\partial x - \partial u/\partial y)$ in 200 hPa is computed in each grid points in the domain of 90°W – 20°W, 5°N – 45°S, during austral summer of 1994 – 2001 period.

An index designated as "COD" represents the number cyclone occurrence density. This index is the numbers of days with $\zeta < \zeta_c$, where this value is computed in each grid point. Several test were performed to determine this threshold ($\zeta_c = -2.5 \times 10^{-5}\ s^{-1}$) in the area of study. This value was representative of the occurrence of the ULCVs.

To analyze the rainfall and cyclonic vorticity spatial distribution three target areas (Figure 1) are defined. They represent three subregions with distinct regimes of rainfall: the northwestern NEB (**A**: 5°S - 10°S e 45°W - 48°W), central Bahia state (**B**: 10°S - 13°S e 40°W - 44°W) and the semiarid of the NEB (**C**: 5°S - 9°S e 37°W - 41°W).

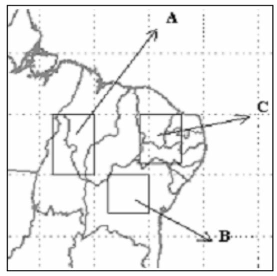

Figure 1. Target Area A (5°S-10°S, 45°W-48°W), B (10°S-13°S e 40°W-44°W) and C (5°S-9°S e 37°W-41°W).

3. Results

The Figure 2 shows the distribution of COD for all the period of austral summer of 1994 – 2001. It can be observed that practically all NEB is affected by a high density of cyclonic events. An exception is for northwest part of NEB (subregion A). The highest values of COD associated with the occurrence of ULCV are found in the region between 22.5°W – 47.5°W and 2.5°S – 17.5°S. The red, orange yellow and green colors refer to high densities of cyclonic events in Southern Hemisphere.

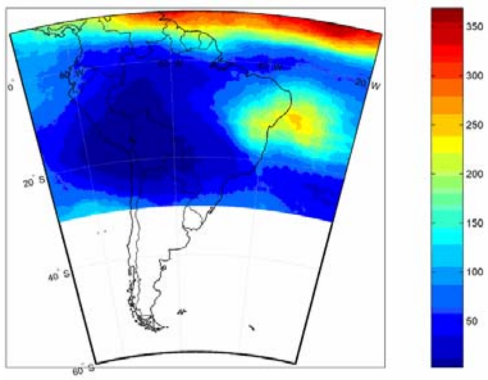

Figure 2. Spatial distribution of the number of days with relative vorticity <-2,5 x$10^{-5}s^{-1}$ (COD) for the summer periods (December to March) of 1994 to 2001.

To determine the occurrence of El Niño and La Niña events in the period of study, the Southern Oscillation index (SOI) was analyzed. Figure 3 depicts the time series of SO index, highlighting in yellow the summer in study (December-March of 1994 -2001).

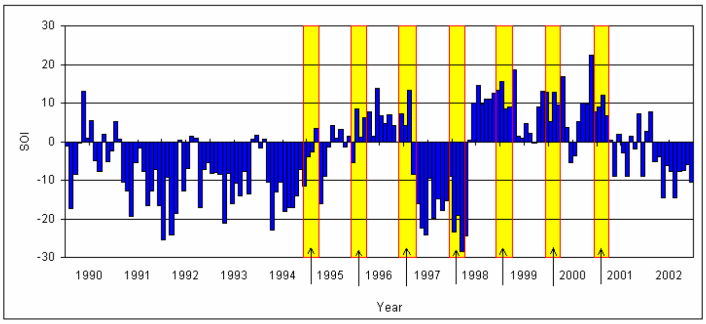

Figure 3. South Oscillation index of 1990-2002, the yellow sectors refer to the months of December-March of 1994-2001.

The classification of the phenomenon ENSO for the period of study in agreement with NOAA is shown in Table 1.

Table 1 – Years of El Niño and La Niña events during December-March of 1994 -2001 period

Year	**Date**
Moderate El Niño	dez1994-mar1995
Weak La Niña	dez1995-mar1996
Neutral	dez1996-mar1997
Severe El Niño	dez1997-mar1998
Moderate La Niña	dez1998-mar1999
Moderate La Niña	dez1999-mar2000
Moderate La Niña	dez2000-mar2001

Figures 4a-4g show the densities of occurrence of the cyclonic vorticity for each summer in the period of study. Seven summers (1994 to 2001) were examined, two El Niño events, two La Niña events, where, one of them (1998-2001) was more prolonged (three summers) and a neutral year. In general, it was showed that the higher values of COD occurred in the subregions **B** and **C**, reaching in some years, values between 40 and 50 days with cyclonic vorticity stronger than – 2.5 x 10^{-5} s^{-1}. The subregion **A (**northwest part of NEB) was less affected by the centers of cyclonic vorticity.

An interannual variation of the distribution of the occurrence of cyclonic vorticity associated with ENSO events is evident. It was showed that the occurrence (COD) of ULCV/TUL in years of moderate or strong El Niño is high, reaching approximately 50 events in the moderate El Niño year (1994/95) (Fig. 4a) and 55 in the year of strong El Niño (1997/1998) (Fig. 4d). The eastern part of the subregion B was more affected in the summer of moderate El Niño, including the northeastern Bahia and the states of Pernambuco, Paraiba e Rio Grande do Norte. On the other hand, the subregion C (semiarid) was more affected in the strong El Niño years. However, in this event the higher density of occurrence of vorticity was located over the Atlantic Ocean.

During La Niña events the COD associated with ULCV/TUL decrease significantly, specifically, in the weak (1995/96) La Niña year (Fig. 4b) and the prolonged cases of the moderate La Niña (dez1998-mar1999 and dez1999-mar2000) (Fig.4e, 4f and 4g), reaching approximately 30 events. In the mature stages of the moderate Niña (dez2000-mar2001) (Fig. 4g), the behavior is different. The number of cyclonic events is comparable to the years of El Niño. It was approximately 50 events per summer. Regarding the spatial position of the maximum cyclonic density it was observed that only the subregion B (central Bahia) was weakly affected. In 1998/99 La Niña (Fig. 4e) the highest frequency is positioned in the interior of the Bahia and in the summers 1995/96 and 1999/2000, the position of maximum COD are over the adjoining Atlantic South ocean. On the other hand, for the 2000/2001 event the area B was affected significantly, extending into the ocean.

The neutral year (1996-1997) (Fig. 4c) presented 40 cyclonic events approximately, not sufficiently high to consider high frequency. The subregions more affected were B and C, extending into the neighboring ocean.

To examine the characteristics of ULCV and the rain occurrence for the events ENSO were analyzed for some specific cases.

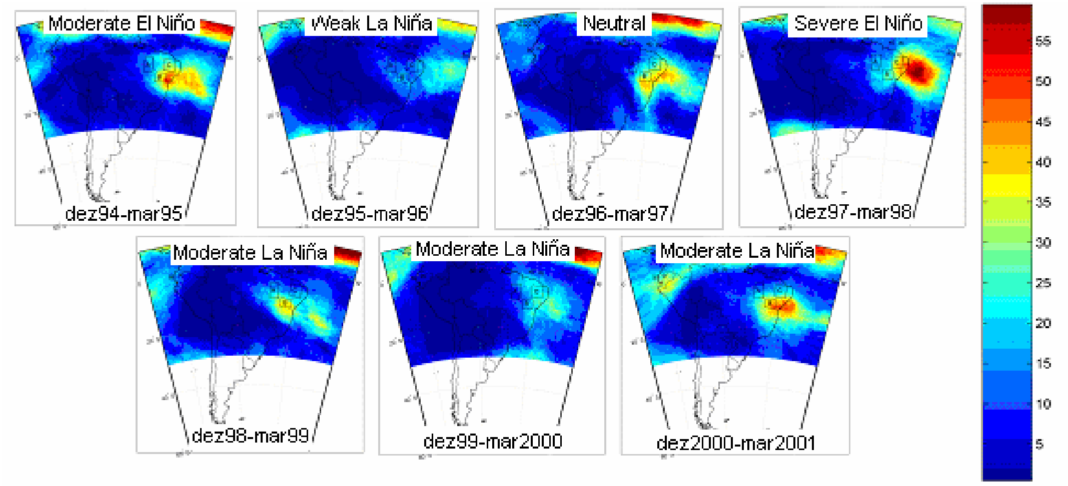

Figure 4. Spatial distribution of the number of day with relative vorticity $<-2.5x10^{-5}s^{-1}$ (COD), for the period of December/2000 - March/2001.

3.1 Case 1 (27/12/95 - 05/01/1996) Weak La Niña

Figure 5 shows the satellite images during the lifetime of a ULCV. It was observed in the first days that the subsidence area (dark area in the image) is over the Atlantic Ocean, while a band of cloudiness in its western sector (border of ULCV) is over NEB. On the third day, the subsidence area of ULCV moves into the continent. Finally, the subsidence area in the centre of ULCV extends on the whole NEB in the last three days of life.

The sequence of 200 hPa streamlines illustrating large-scale flow pattern related to ULCV is shown in Figure 6. The 200 hPa circulation pattern on 27 December, 1995, shows the ULCV positioned on Atlantic Ocean, extending in a small horizontal area. On 30 December 1995, the ULCV stretches westwards, inside of continent. On 02 January, 1996, the ULCV area is reduced and its center is positioned over the coast of NEB. The vortex reaches the NEB on 05 January.

The 200 hPa circulation patterns show a zonally extended Bolivian High (BH). It is important to observe the amplification eastward of the ridge associated to BH over the southwestern Brazilian coast. For this case, the mechanism of formation of ULCV is due to the presence of SACZ. The SACZ was formed on 26 December, one day before the formation of ULCV (Climanalise, 1995). Apparently, the latent heat release along SACZ intensifies the ridge and by vorticity conservation a cyclonic center would developed to the northeast (Ramírez et al., 1999).

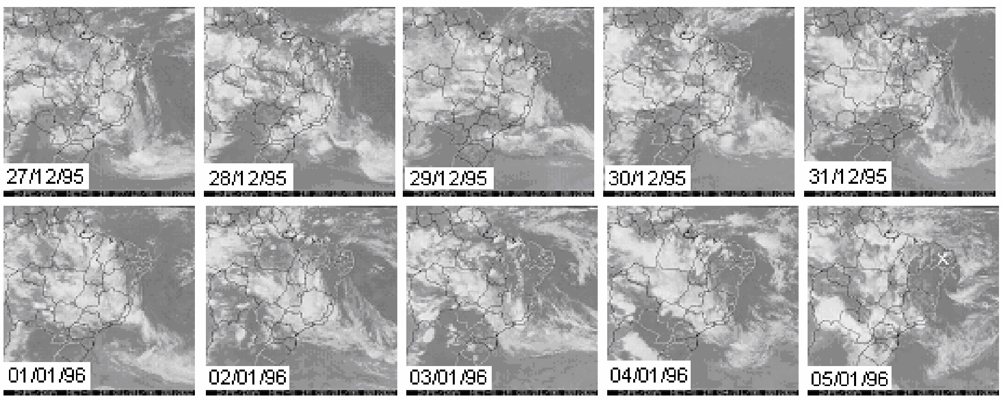

Figure 5. Sequence of satellite images for 27 December 1995 to 05 January 1996 at 00 Z, representing the lifetime of a ULCV. In the last image X is the center of the ULCV.

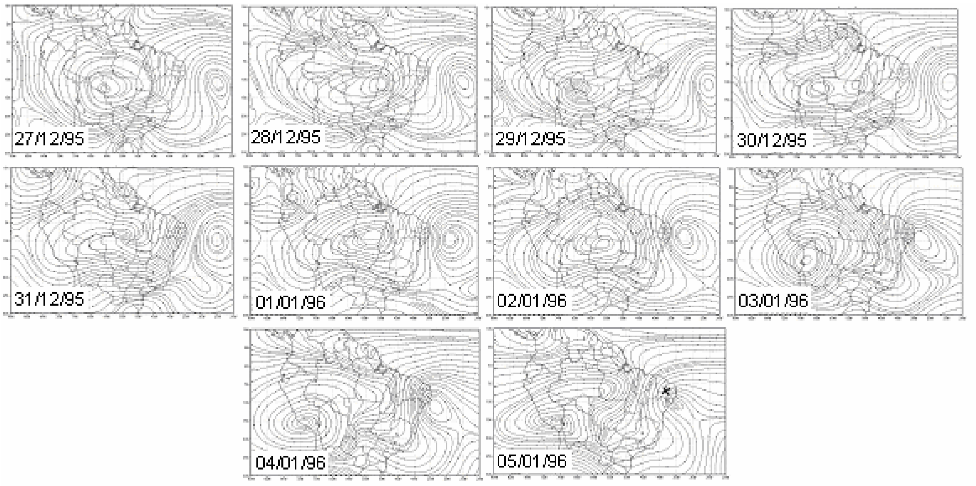

Figure 6. Streamlines and vorticity (200 hPa) for the lifetime of ULCV (27/12/1995 to 05/01/1996) the 00 Z. In the last panel X is the center of the ULCV seen in the field of relative vorticity.

The intensity (IC), area (C) and position (PO) parameters of ULCV are presented in the Table 2. The largest area and intensity of ULCV was observed in the seventh day, 02 January, reaching 2541000 km^2 and –7.6 x 10^{-5} s^{-1}, respectively. In the last day of the life cycle, smallest intensity of the system, presenting –5.2 x 10^{-5} s^{-1}, was observed, however, the smallest area (1554000 km^2) was observed on 02 December.

Table 2. Intensity (IC), area (C) and position (PO) of the ULCV in his lifetime, 27 December 1995 to 05 January 1996.

Date	IC($10^{-5}s^{-1}$)	C(km^2)	PO(Lat; Lon)
27/12/95	-6.67	1820000	(7.5°S; 27.5°W)
28/12/95	-6.86	1645000	(7.5°S; 25.0°W)
29/12/95	-6.78	1653000	(10°S; 22.5°W)
30/12/95	-6.84	1833000	(10°S; 22.5°W)
31/12/95	-7.21	2141000	(10°S; 25.0°W)
01/01/96	-6.86	2366000	(7.5°S; 30.0°W)
02/01/96	-7.55	2541000	(7.5°S; 32.5°W)
03/01/96	-6.42	2072000	(7.5°S; 35.0°W)
04/01/96	-6.35	1537000	(10°S; 35.0°W)
05/01/96	-5.15	1554000	(7.5°S; 37.5°W)

Figure 7 displays the daily mean precipitation of the subregions **A**, **B** and **C** for the lifetime of ULCV. It was observed that the subregion **A** presented significant precipitation in all lifetime of the system, reaching a value above 20 mm/day on 01/01/96. In the others days, the subregion A also was affected by the border of ULCV, except on 02 and 03 January, where smaller values of 4 mm/day were observed.

The subregion B presented significant precipitation in the first days of lifetime of ULCV, when this was still positioned on ocean, that is, the convective cloud band near the border of the system positioned over this subregion. On January 01 there was a decrease, reaching values close to zero. The subregion **C** presented smaller precipitation of 4 mm/day for the whole period, this suggest that the subsidence in the centre of ULCV was over this subregion or that this area was little affected by the eastern or northeastern border of ULCV.

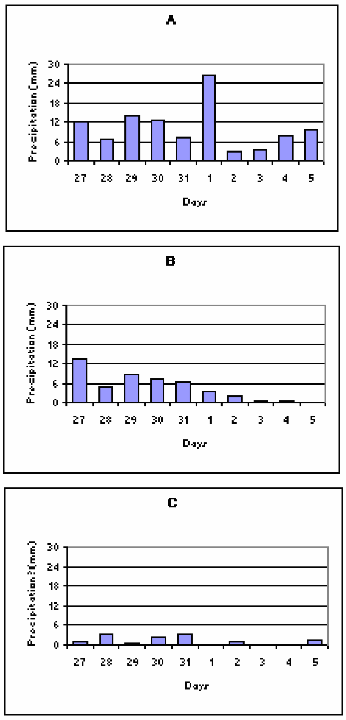

Figure 7. Daily mean precipitation to the subregions A, B and C for period from 27 December, 1995 to 05 January, 1996.

3.2 Case 2 (23/02/98 - 02/03/1998) Severe El Niño

The Figures 8 and 9 shows satellite images, streamlines and relative vorticity at 200 hPa for this case, similarly to the previous case, they show the areas of deep cloudiness, subsidence and of maximum cyclonic vorticity.

For this case, the 200 hPa circulation pattern associated with the vortex is different. On 23 February, the HB presents a northwest-southeast direction with its amplified ridge over southwestern Brazilian, due to the incursion of a front system. This mechanism of formation was the same proposed by Kousky and Gan (1982). On the following days, it can be observed that HB extend eastwards and moving for the south. This type of situation favors the inland displacement of UCLV (Ramírez et al., 1999).

The maximum centre of cyclonic vorticity doesn't necessarily coincide with the centre of closed circulation in the field of streamline (Fig. 9). In the initial and mature stages the maximum vorticity center is located over northern part. In the dissipation phase, the maximum vorticity center (IC) and the closed circulation were in the same position.

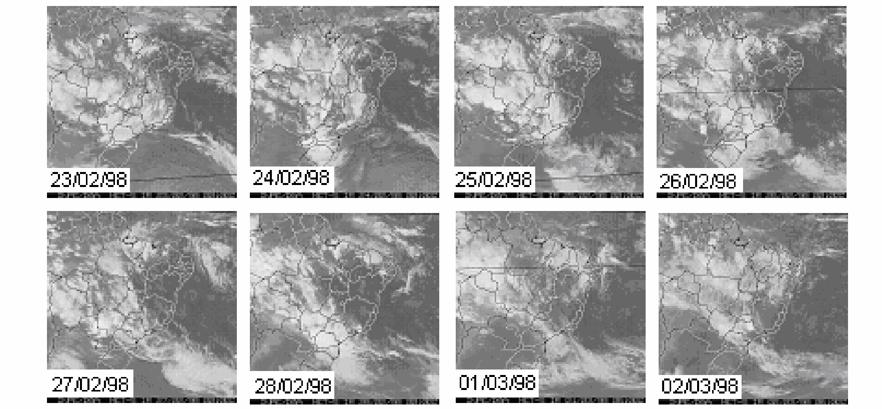

Figure 8. Sequence of satellite images from 23 February 1998 to 02 March 1998, at 00 Z, representing the lifetime of a ULCV.

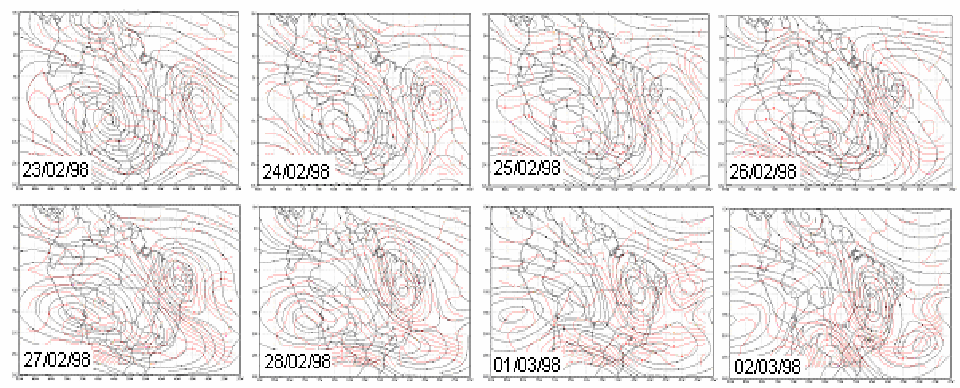

Figure 9. Streamlines and vorticity ($x10^{-5}s^{-1}$) (200 hPa) for the lifetime of ULCV (23/02/1998 to 02/03/1998) the 00 Z. In the last panel X is the center of the ULCV seen in the field of relative vorticity.

The parameters for this case are shown in the Table 3. It was evident that on 28/02/98 the ULCV reaches its maximum cyclonic vorticity ($-6.72x10^{-5}s^{-1}$). In this case, the IC was higher than in the first case. The maximum area of ULCV was of 5936000 km^2, and lifetime was 8 days.

Figure 10 shows that all the subregions presented a decrease in the rainfall to below 10 mm/days. The subregion **A** reaches 8 mm/day in 01/03/98 and between 5 and 7 mm/day in the period on 24, 25 and 26 February. This suggests that the border of the ULCV influenced this subregion. The areas B and C suffered influences of the center of the UVLC, presenting several days without rainfall, or with values close to zero. That is due to the ULCV position inland by four days.

Table 3. Intensity (IC), area (C) and position (PO) of the ULCV during its lifetime, from 23 February 1998 to 02 March 1998.

Date	IC($x10^{-5}s^{-1}$)	C (km^2)	PO (Lat; Lon)
23/02/98	-5.74	1575000	(10°S; 32.5°W)
24/02/98	-5.87	1706000	(7.5°S; 32.5°W)
25/02/98	-4.42	5390000	(10°S; 37.5°W)
26/02/98	-5.59	5936000	(7.5°S; 40°W)
27/02/98	-6.56	3893000	(10°S; 40°W)
28/02/98	-6.72	2821000	(10°S; 42.5°W)
01/03/98	-5.90	2346000	(10°S; 45°W)
02/03/98	-5.33	1778000	(12.5°S; 45°W)

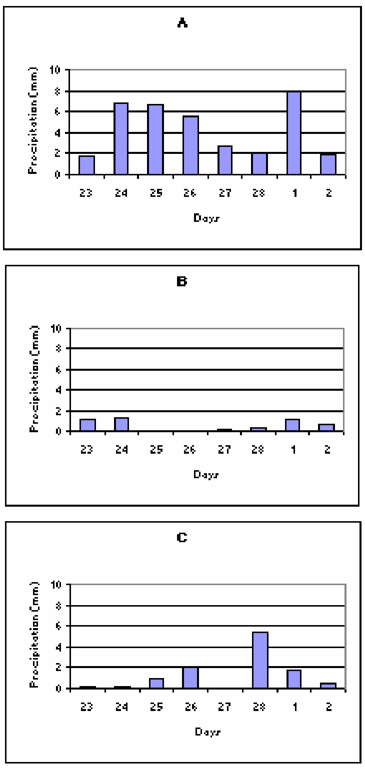

Figure 10. Daily mean precipitation for the subregions A, B and C for the period from 23 February 1998 to 02 March 1998.

4. Final considerations

The results raised several question regarding the presence of ULCV in years ENSO. When we analyzed the density of occurrence of days with cyclonic vorticity it was possible to observe that specifically for these cases of year El Niño the density of number of days with cyclonic vorticity was higher (50 days) and for years of La Niña it was smaller (30 days). However, it was observed that for the dissipation phase of the prolonged event of moderate La Niña the number of days with cyclonic vorticity had a tendency to increase. The eastern part of Bahia and subregion C (semiarid) were the most affected by the subsidence center of ULCV in the years of El Niño. When analyzed the specific cases, in year of La Niña it was observed that the subsidence center (or maximum cyclonic vorticity center) remained more time on ocean and eastern part of the NEB, being these areas that presented smaller rain occurrence. On the other hand, the interior of the NEB (subregion A) presented larger rainfall. In the case of El Niño the configuration was different, during its lifetime the ULCV penetrated to the continent. In other words, the subsidence center affected great part of the area of the Northeast, for that reason, the rains were smaller than in the previous case.

Specific characteristics, as the formation, intensity and spatial extension of ULCV in ENSO periods, need to be investigated more thoroughly considering a larger number of cases.

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