Proceedings of 8 ICSHMO, Foz do Iguaçu, Brazil, April 24-28, 2006, INPE, p. 2027-2031.

THE ROLE OF THE UPPER TROPOSPHERIC CYCLONIC SYSTEMS IN THE NORTHEAST OF BRAZIL RAIN INHIBITION

Lígia Alves da Silva and Prakki Satyamurty[2]
1,2 Instituto Nacional de Pesquisas Espaciais – INPE, São José dos Campos, SP, Brazil

For a long time it is known that the spatial and temporal variability of the rainfall in Northeast Brazil (NEB) is influenced by the upper level cyclonic vortex (ULCV). However, there are no studies that establish a quantitative relation between the rainfall and the characteristics of the ULCVs. In this paper we investigate the role of the ULCVs in rain inhibition over NEB. We consider here both upper level cyclonic vortices and upper level troughs as upper level cyclonic systems (ULCS). They are large-scale low-pressure systems with a cold core in the upper troposphere and frequently occur during the austral summer. They are accompanied by convective clouds on their peripheries and clear skies in their centers. In order to identify the occurrence of ULCS, we use daily averaged zonal (u) and meridional (v) components of the wind at the 200 hPa level from NCEP-NCAR reanalysis, and infra-red images from METEOSAT-3, METEOSAT-5 and GOE-8 satellites. We use daily precipitation data from the Brazilian National Water Board (ANA). The precipitation inhibition is evaluated in three sub-regions of the NEB (the northwest of the NEB, central Bahia and the semiarid NEB) for the austral summers (DJFM) of 1994-2001 (849 days). We define the border of the cyclonic system as the $\zeta = -2.5 \times 10^{-5}\ s^{-1}$ isoline. The daily precipitation of each subregion is categorized into three classes, weak, moderate and intense, based on the frequency distribution of precipitation in the subregion. The statistical analysis shows a clear reduction in the number of intense and moderate precipitation days during the periods when the ULCV is situated over the subregion.

1. INTRODUCTION

The rainfall regime of this region presents a strong spatial and temporal variability (Kousky 1979). Many studies have investigated this variability to understand the physical and dynamical processes responsible for extreme conditions such as droughts and floods. The intraseasonal variability of weather conditions NEB are due to the influence of meteorological systems such as Intertropical Convergence Zone (ITCZ) (Uvo 1989), upper tropospheric cyclonic vortices (ULCV) (Kousky and Gan 1981), easterly waves (Ferreira et al. 1990) and instability lines (Cohen 1995).

According to Kousky the coastal areas in the east of the region may receive 2000 mm or more of rainfall annually whereas some interior parts of NEB receive as little as 400 mm. The three-month rainiest period varies from MAM in the interior Northeast Brazil, MJJ in the eastern coastal strip and DJF in the southern parts of the region (Rao and Hada 1990). The seasonal rainfall in the semiarid NEB has a strong bearing on the preseasonal rainfall (Hastenrath 1990).

On the intraseasonal scale a large portion of the spatial and temporal variability of rainfall is attributed to the ULCS formation and dissipation, which is one of the principal atmospheric circulation systems in austral summer. An interesting relationship between the upper vortex and the precipitation is heuristically observed in the satellite imagery. The imagery shows convective clouds on the boarder of the vortex and clear skies in its core (Kousky and Gan 1981).

Dean (1971) and Aragão (1975) were the first observational studies on the vortex in the tropical South Atlantic. They showed that situations of heavy rainfall in NEB and neighborhood are associated with the vortex. Gan and Kousky (1981) observed that the upper vortices originate in the Atlantic Ocean between 20°-45°W and 0°-28°S and as they move into Brazil they produce copious amounts rainfall in their northern and northeastern sectors and little convective activity in the southern and central areas of NEB.

Frank (1966) observed that the life cycle of the vortex varies considerably. Some vortices remain stationary for a week or longer while others dissipate within a few hours. Ramirez (1996) observed that the life cycle of the vortex varies with the season of the year, having longer life (9.5 – 10.6 days) in summer and shorter life in spring (4.6 – 6.0 days). The mean duration of the vortex

1- Corresponding author address: Lígia Alves da Silva, Departament of Meteorology, Instituto Nacional de Pesquisas Espaciais, São José dos Campos, SP, Brazil. E-mail:Ligia@cptec.inpe.br

is 7.1 days. The individual vortices, however, may have durations ranging from 3 days to 18 days.

The irregularity of rainfall in Northeast Brazil affects the agriculture of the region, destroying the crops and causing unemployment and famine. For adequate planning of the socio-economic activities of the region reliable short and medium range meteorological forecasts and climatological forecasts are necessary.

In this study a statistical analysis of the rainfall in three distinct subregions of NEB is performed to show the influence of the upper air vortex on the distribution of the moderate and heavy rainfalls.

2. DATA AND METHODOLOGY

The reanalysis datasets from the (National Centers for Environmental Prediction (NCEP)-National Center for Atmospheric Research (NCAR), available at the homepage of the institution (www.cdc.noaa.gov) are used for the analysis. The variables used are the zonal and meridional components of wind (u, v) at 200 hPa level with a resolution of 2.5° longitude and 2.5° latitude. This resolution is considered adequate since the upper vortices have horizontal dimensions of 10°. The season considered is DJFM for the seven-year period 1994-2001.

The relative vorticity $\zeta = (\partial v/\partial x - \partial u/\partial y)$, at 200 hPa, is calculated in the domain 90°W - 20°W, 5°N - 45°S, for the whole period of study . The cyclonic areas over NEB and the adjoining South Atlantic are identified and the following parameters are calculated: The area of the cyclonic vortex (C), the intensity (IC) and the coordinates of the maximum cyclonic vorticity point (PO). The area extent is given by the area of the $\zeta = -2.0\text{x}10^{-5}\ s^{-1}$ closed isoline (inside which the vorticity is negative or cyclonic). The maximum value of cyclonic vorticity observed in this area is the intensity.

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 for the period 1994 - 1996 and GOES-8 for the period 1997 - 2001, at 00 UTC. The cloud imagery is available from http://www.cptec.inpe.br. This verification is important to eliminate spurious vortices introduced by the analysis without any support from the cloud imagery.

Based on the previous studies on the rainfall regime in NEB (Kousky and Chu, 1978; Alves and Repelli, 1992; Rao et al., 1993; Rao and Hada, 1990), the present study chose three distinct subregions of NEB. Three retangular areas (A) 5°S-10°S; 45°W-48°W, (B) 10°S-13°S; 40°W-44°W and (C) 5°S-9°S; 37°W-41°W, are selected to represent the three sub-regions with distinct rainfall characteristics in NEB, namely, northwestern NEB, central Bahia and semi-arid NEB, respectively, and are called Target Areas (TAs). The daily rainfall data for NEB are available from ANA. The number stations in each one of the three TAs is not constant. Area A has data for 40 to 44 stations, area B 34 to 37 stations and area C 64 to 70 stations.

The total number of days in the 7 austral summers studied (DJFM) is 849. The daily mean precipitation over the three TAs is calculated for the 849 days. From the aerial mean daily rainfall values over the three areas frequency distribution in classes of rainfall with 1 mm/day intervals are prepared. Three categories of precipitation are defined based on the cumulative frequency distribution: Categories I, II e III, representing light or no rain, moderate rain and heavy rain. The 66% of the days with least rainfall are weak rain days, the 5% highest rainfall days are intense rain days and the intermediate 29% days are moderate rain days.

3. RESULTS AND DISCUSSION

Figure 1 shows the number of days on which the upper cyclonic vortex influenced NEB in austral summers according to the intensity of the vortex. It can be seen that the intensity of the vortices varies from $-2.5\text{x}10^{-5}\ s^{-1}$ to $-11.0\text{x}10^{-5}\ s^{-1}$. A large number of vortices fall in the intensity range from $-2.5\text{x}10^{-5}\ s^{-1}$ to $-7.5\text{x}10^{-5}\ s^{-1}$. Vortices with intensities greater than $-8.0\ \text{x}10^{-5}\ s^{-1}$, the frequency is less, only 10 in 861 days. The total number of days with vortex ($\zeta \leq -2.5\text{x}10^{-5}\ s^{-1}$) affecting the region are 500 in 849 days.

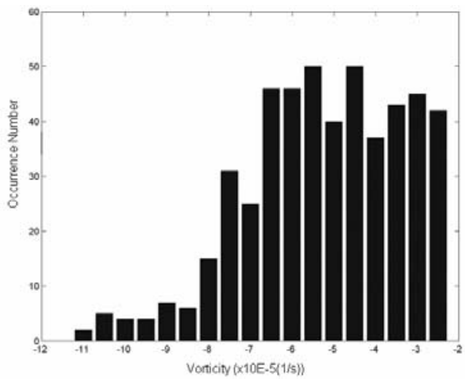


Figure 1. Number of days on which cyclonic vortices influenced NEB during austral summers of 1994 - 2001.

Figure 2 shows the number of days according to the area of the cyclonic vorticity affecting NEB. The vortices with areas in the range of 15 - 25 x 10^5 km^2 are frequent (400 days). Vortices larger than 25 x 10^5 km^2 have occurred on more than 40 days. The frequency decreases rapidly for larger vortices.

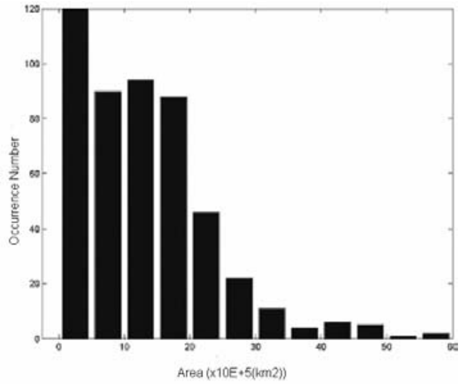


Figure 2. Number of occurrences versus the size of the cyclonic system over Northeast Brazil (NEB) in austral summers of 1994 - 2001.

Table 1 shows the 4-month mean rainfall as compared to the total annual rainfall for the Target Areas A, B and C, representing the subregions, northwestern NEB, interior Bahia and the semiarid NEB, respectively. It can be seen that the semiarid as well as northwestern NEB receive approximately 60% of the annual rainfall in DJFM. According to Gan (1982), Ramirez (1996) and Paixão (1999) the rainfall amounts of this 4-month period are influenced by the upper cyclonic vortices, which justifies the present study that examines influence of the vortices on the rainfall in the interior of NEB.

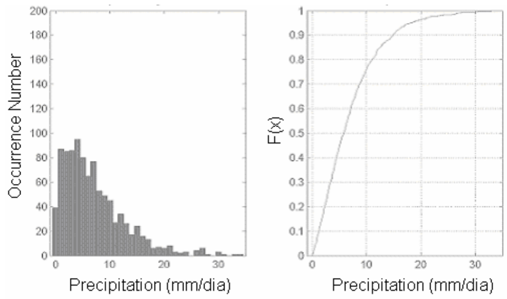
Table 1. Contribution of DJFM rainfall (mm) for the annual rainfall in three sub-regions of NEB represented by the Target Areas A, B and C.

Target Area	Annual (mm)	DJFM (mm)	%
A	1399	857	61
B	715	397	56
C	637	362	57

The frequency distribution and cumulative frequency of the rainfall in Target Area A according to the intensity of rainfall are shown in Figure 3. The highest frequencies are observed in the interval 1 - 8 mm/day with approximately 560 occurrences. The figure shows that the larger the precipitation the less the frequency, especially beyond 18 mm/day. It is important to remember that the studies of Kousky and Chu (1978) showed that the northwestern NEB receives a total of 1000 mm annually and the rainfall distribution there is different from the semiarid NEB.

It can be verified from the panel (b) of Figure 3 that 75% de occurrences of rain had volumes less than 10 mm/day and 97% of the occurrences had volumes less than 20 mm/day. In only 3% of the cases the daily average rainfall presented volumes greater than 20 mm/day. Based on this figure three categories of rainfall are defined:

- Category I (0% – 66%), 560 days: 0.0 ≤ precipitation < 7.94 mm/day;
- Category II (66% – 95%), 246 days: 7.94 mm/day ≤ precipitation < 18.31 mm/day;
- Category III (95% – 100%), 43 days: precipitation ≥ 18.31 mm/day.



(a) (b)

Figure 3. Frequency of occurrence of rainfall in the Target Area A in different classes of rainfall (mm/day) (a) and relative cumulative frequency (b), for the period December through March 1994 - 2001.

The cyclonic system (ζ<-2.5x10^{-5} s^{-1})(ULCS) was present right over the Target Area A on 399 days (47% of total) out of 849 days. Table 2 shows the number of days and their percentage frequency of rainfall in the three categories during those 399 days. It is verified that Category I rainfall (less than 7.94 mm/day) occurred on 302 days (76%). Category II rainfall (7.94 – 18.31 mm/day) occurred on 88 days, and category III rainfall occurred only on 2,3% of the 399 days. Of the 43 occurrences of the Category III rainfall only 9 (21%) happened when the cyclonic system was directly over the Target Area. It is important to note that while the ULCS was present on 47% of the days the heavy rainfall days were only 21% of the total. This means that when the cyclonic system is present over the Target Area, the heavy rainfall (category III) days are reduced more than on the days when the cyclone system was not present.

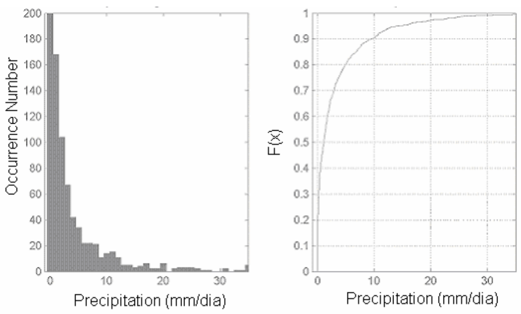
Table 2. Precipitation frequency in the three categories of daily rainfall (I, II e III) in the Target Area A when the cyclonic system (ζ<-2.5x10^{-5} s^{-1}) is positioned over A.

Precipitation (Pr)	Number of days	%
Pr < 7.94 mm/day (I)	302	75.7
7.94 mm/dia ≤ Pr < 18.31 mm/day (II)	88	22.0
Pr ≥ 18.31 mm/day (III)	9	2.3
Total	399	100.0

The behavior of the rainfall over the Target Area B is presented in Figure 4 which shows that 60% the occurrences were in the interval 0 - 3 mm/day. Thus, the sub-region receives less precipitation, compared to Area A. Beyond the value of 13 mm/day the frequency is less than 8 per interval. Such a behavior was found by Kousky and Chu (1978). They showed that the rainfall in the interior of Bahia assumes values typical of the semiarid NEB, the annual amounts varying between 400 and 800 mm.

Panel (b) of Figure 4 shows that 80% of the occurrences had volumes less than 5 mm/day, and 90% had less than 10 mm/day. Based on this figure the three Categories, weak, moderate and heavy rainfall, in the Area B are defined as:

- Category I (0% – 66%), 560 days: 0.0 ≤ precipitation < 2.3 mm/day;
- Category II (66% – 95%), 246 days: 2.3 mm/day ≤ precipitation < 13.6 mm/day;
- Category III (95% – 100%), 43 days: precipitation ≥ 13.6 mm/day.



(a) (b)

Figure 4. Frequency of occurrence of rain in the Target Area B in different classes of rainfall (mm/day) (a) and cumulative frequency (b), for December through March 1994 – 2001.

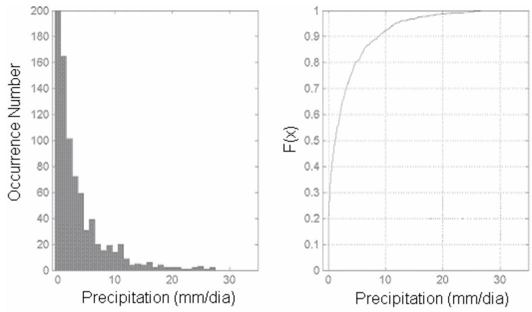
Table 3. Precipitation frequency in the three categories of daily rainfall (I, II e III) in the Target Area B when the cyclonic system (ζ<-2.5x10^{-5} s^{-1}) is positioned over the Target Area B.

Precipitation (Pr)	Number of days	%
Pr < 2.3 mm/day (I)	370	77.6
2.3 mm/day ≤ Pr < 13.6 mm/day (II)	97	20.3
Pr ≥ 13.6 mm/day (III)	10	2.1
Total	477	100.0

The rainfall characteristics of the Target Area C are shown in Figure 5. According to Kousky and Chu (1978), the behavior of the rainfall in the semiarid of NEB are similar to the central Bahia region represented by Area B. Area C presented only 7 cases with rainfall > 13 mm/day. This shows that the two subregions show the same rainfall regime during summers.

The three Categories of rainfall for the Area C are defined as:

- Category I (0% – 66%), 560 days: 0.0 ≤ precipitation < 2.45 mm/dia;
- Category II (66% – 95%), 246 days: 2.45 mm/day ≤ precipitation < 11.71 mm/day;
- Category III (95% – 100%), 43 days: precipitation ≥ 11.71 mm/day;



(a) (b)

Figure 5. Frequency of occurrence of rain in the Target Area C in different classes of rainfall (mm/day) (a) and cumulative frequency (b), for December through March 1994 – 2001.

Table 4 shows the number of days in the three categories of rainfall in the target area C in the 503 days in which the Northeast was under the influence of ULCS. It is easily verified that heavy precipitation occurred only on 17 days, although the ULCS was directly over the Target Area on 60% of the days. The reduction in rainfall, especially Category III rainfall, occurred because of the influence of the subsidence in the center of the ULCS.

Table 4. Precipitation frequency in three categories I, II, III in the Target Area C when the cyclonic system (ζ<-2.5x10^{-5} s^{-1}) is positioned over the subregion.

Precipitation (Pr)	Number of days	%
Pr < 2.45 mm/dia (I)	349	69.4
2.45 mm/dia ≤ Pr < 11.71 mm/dia (II)	137	27.2
Pr ≥ 11.71 mm/dia (III)	17	3.4
Total	503	100.0

4. CONCLUSIONS

This study attempts to analyze the influence of the ULCS on the reduction of rainfall in three target areas in Northeast Brazil. For each one of the three Target Areas three categories of rainfall are defined, based on the frequency distribution of the mean daily precipitation in the areas. Category I, II and III represent light, moderate and heavy precipitation. The three Target Areas A, B and C are situated in western Northeast, central Bahia and the semi-arid, respectively. While the category I rainfall is more frequent in all the three target areas, the areas B and C showed a larger percentage of days influenced by the subsidence associated with ULCS. The subsidence area was right over Area B on 477 days reducing the daily rains to below 2.3 mm/day, a result agreeing with the findings of Chaves and Cavalcanti (2001). The authors have shown that the dry and wet periods in Northeast are associated with the positioning of the ULCS. In a rainy situation the cyclonic vorticity center is positioned in the Atlantic away from the continent, whereas in a dry situation the center is positioned over the continent, in Northeast Brazil. The cyclonic center was situated over the Target Area C on 503 days causing daily precipitation values to limiting to 2.45 mm/day on 349 days, which shows that the subsidence associated with the center of the ULCS caused inhibition of rainfall. This result agrees with Kousky and Gan (1981) showing that the center of the ULCS is a subsidence region. The rainfall over the Target Area A also showed some significant characteristics. There the rainfall was less than 7.94 mm/day on only 302 days. It is interesting note that this value is three times larger than the upper limit of light rain in Areas C and B. That is Target Area A (the western flank of Northeast) is distinct from the dry interior.

5. REFERENCES

Alves, J. M. B.; Repelli, C. A., 1992: A variabilidade pluviométrica no setor norte do Nordeste e os eventos El Nino-Oscilação Sul (ENOS). *Revista Brasileira de Meteorologia*, v. 7, n. 2, p. 583-592.

Aragão, J. O., 1975: *Um estudo a estrutura das perturbações sinóticas do Nordeste do Brasil.* (INPE-789-TPT/017). Dissertação (Mestrado em Meteorologia). São José dos Campos, INPE.

Chaves, R. R., Cavalcanti, I. F. A., 2001: Atmospheric circulation features associated with rainfall variability over Southern Northeast Brazil. *Mon. Wea. Rev.*, v.129, p. 2614-2626.

Cohen, J. C. P., Silva Dias M. A. F. and Nobre C., 1995: Enviromental conditions associated with amazonian squall lines: A case study. *Mon. Wea. Rev.*, p. 3163-3174.

Dean, G. A., 1971: *Three dimensional wind structure over South America and associated rainfall over Brazil.* (LAFE-164). Dissertação. São José dos Campos, INPE.

Ferreira, N.J., Chan, C.S. & Satyamurty, P., 1990: Análise dos distúrbios ondulatórios de leste sobre o oceano Atlântico Equatorial Sul, *XI Congresso Bras. Meteorologia*, Rio de Janeiro, p. 462-466.

Frank, N. L., 1966: The weather distribution with upper tropospheric cold lows in the tropics. *U.S Weather Bureau. Southern Region, Technical Memorandum*, n. 28.

Gan, M. A., 1982: *Um estudo observacional sobre as baixas frias da alta troposfera nas latitudes subtropicais do Atlântico Sul e Leste do Brasil*. (INPE -2685-TDL/126). Dissertação (Mestrado em Meteorologia). São José dos Campos, INPE.

Hastenrath, S. 1990: Prediction of Northeast Brazil Rainfall Anomalies. *J. Climate*: Vol. 3, No. 8, pp. 893–904.

Kousky, V. E., 1979: Frontal influences on Northeast Brazil. *Mon. Wea. Rev.*, v. 107, n. 9 p. 1140-1153.

Kousky, V. E.; Chu, P. S., 1978: Fluctuations in annual rainfall for Northeast Brazil. *Bull. Amer. Meteor. Soc.*, Japan, v. 56, p. 457-465.

Kousky, V. E.; Gan, M. A., 1981: Upper tropospheric cyclonic vortices in the tropical South Atlantic. *Tellus*, v. 33, n. 6, p. 538-551, Feb.

Paixão, E. B., 1999: *Caracterização do vórtice ciclônico de ar superior sobre o Nordeste do Brasil.* Dissertação (Mestrado em Meteorologia). São Paulo, IAG/USP.

Ramirez, M. C. V., 1996: *Padrões climáticos dos vórtices ciclônicos de altos níveis no Nordeste do Brasil.* Dissertação (Mestrado em Meteorologia). São José dos Campos, INPE.

Rao, V. B.; Hada, K., 1990: Characteristics of rainfall over Brazil: Annual variations and connections with the Southern oscillation. *Theoretical and Applied Climatology*, v. 42, p. 81-91.

Rao, V. B.; Lima, M. C.; Franchito, S. H., Sep, 1993: Seasonal and interannual variations of rainfall over eastern Northeast Brazil. *J. Climate*, v. 6, n. 9, p. 1754-1763.

Silva, L. A., 2005: *A Influência dos Vórtices Ciclônicos de Altos Níveis (VCAN) Sobre a Precipitação do Nordeste do Brasil (NEB) e as Características associadas.* Dissertação (Mestrado em Meteorologia). São José dos Campos, INPE.

Spiegel, M. R., 1972: Estatística. McGraw Hill do Brasil. 580 p.

Uvo, C., 1989: *A Zona de Convergência Intertropical (ZCIT) e a Precipitação da região Norte do Nordeste do Brasil*. (INPE-4887-TDL/378). Dissertação (Mestrado em Meteorologia), São José dos Campos, INPE.