브라질 북동부 해안의 악기상: 2004년 1월 사례

Ricardo Sarmento Tenório* · 권병혁** · Luiz Carlos Baldicero Molion* · Alan James Peixoto Calheiros*

Severe Weather Events over Northeastern Brasil:The January 2004 Event

Ricardo Sarmento Tenório* · Byung-Hyuk Kwon** · Luiz Carlos Baldicero Molion* · Alan James Peixoto Calheiros*

요 약

리오그랑디주에서 바이아주 남부까지 약 300 km에 이르는 길고 좁은 브라질 북동부 지역에서는 남동무역풍의 교란, 전선의 침투, 해륙풍 순환 그리고 지형과 수증기 플럭스에 기인하는 국지 대류와 같은 다양한 강수 시스템이 나타난다. 연간 총강수량은 내륙에서는 600 mm, 해안지역에서는 3000 mm의 분포를 보이고 있다. 지역 기후 평균에 5-12배의 강수량이 2004년 1월에 알라고아스주 여러 지역에서 기록되었다. 46,000명의 수재민이 발생했고, 10,000,000 US$의 재산 피해였다. 이 폭우는 27°W, 12°S에서 형성된 UTCV가 1월 내내 브라질 북동부 지역에 머물면서 영향을 미쳤기 때문이라는 것을 GOES 적외선 영상 분석으로 알 수 있었다.

ABSTRACT

The eastern coast of northeastern Brazil (NEB), a coastal land-strip up to 300 km wide and stretching out from Rio Grande do Norte (5°S) State down to the south of Bahia State (17°S), experiences different rain producing systems, such as disturbances in the south-east trade winds, frontal systems penetration, land-sea breeze circulation and local convection associated with the topography and moisture flux convergence. The annual total rainfall ranges from 600 inland to 3000 mm on the coast. Rainfall totals 5 to 12 times the local climatic means were recorded in various regions of Alagoas state in January 2004. It was estimated that 46,000 people were homeless, with material damages exceeding US$10 million as a consequence of the ensuing floods.

GOES infrared images analysis showed that the main weather system responsible for this anomalously high rainfall totals was an Upper Troposphere Cyclonic Vortex (UTCV), which formed at about a 27ºW e 12ºS and remained active for the entire month of January over NEB.

키워드

upper troposphere cyclonic vortex, weather radar, divergence

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Ⅰ. INTRODUCTION

UTCVs are synoptic scale systems with a great impact on the regional weather conditions for they are usually associated with high rainfall events. They are characterized by low pressure and convergence region at upper levels of the troposphere with descending motion in its core. Conversely, high pressure and divergence are found at lower levels, where the western side convection stems from the positioning of a frontal system, usually over the continent. The convection in the UTCV's eastern flank is due to the convergence of the subsiding air with the SE trade winds, generally located over the ocean in the initial stage. UTCVs were described by many authors, among them Palmer(1951) with his pioneering studies, Kousky and Gan (1981), Gan (1982) and Ramirez (1996). The UTCV season spans from November to March, with highest frequency in January, middle of the north hemisphere winter, when the equator-pole thermal gradient is largest in NH. Apparently, they occur in La Ninã years or years in which the equatorial Pacific sea surface temperatures (SST) are close to their climatic mean while the northern Pacific shows positive SST anomalies. Under these circumstances, the frequency of cross equatorial north hemisphere frontal systems affecting even the south hemispheretropics seems to be larger. According to Molion and Bernardo (2002), the necessary conditions for the development of an UTCV is likely to be the presence of frontal systems in low latitudes of both hemispheres simultaneously, with the south hemisphere frontal system (SHFS) enhancing moist flux convergence over entire NEB. This work aimed at describing the prevailing synoptic situation in which the UTCV developed and maintained its activity in producing the observed anomalous rain.

Ⅱ. UTCV PHENOMENOLOGY

UTCVs are synoptic scale systems with a great impact on the regional weather conditions for they are usually associated with high rainfall events. They are characterized by low pressure and convergence region at upper levels of the troposphere with descending motion in its core. Conversely, high pressure and divergence are found at lower levels, where the western side convection stems from the positioning of a frontal system, usually over the continent. The convection in the UTCV's eastern flank is due tothe convergence of the subsiding air with the SE trade winds, genrally located over the ocean in the initial stage

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Ⅲ. DATA

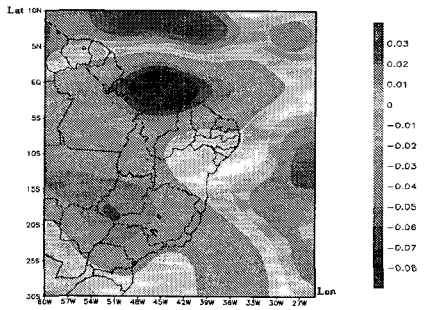
Data from the NCEP's (National Centers for Environmental Predictions) Reanalysis and Meteorological Radar System of the State of Alagoas (SIRMAL) were used to analyze the synoptic situation of January 2004. Conventional rain gage data were provided by the Directory of Hydrology and Meteorology of the Secretary for Environmental and Water Resources of Alagoas State (DHM-SER/AL) and GOES satellite images were taken from CPTEC/INPE site. GrADS was used to display the fields of the selected meteorological variables such as wind speed and direction, outgoing long wave radiation (OLR) and isobaric vertical motion.

Ⅳ. RESULTS

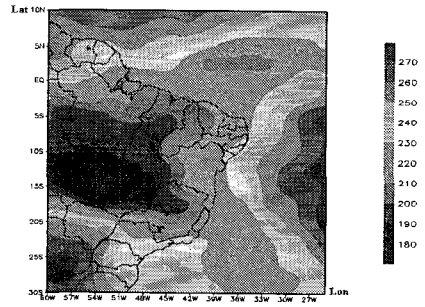
Fig. 1(a) shows the mean 200 hPa vertical velocity omega for January, 2004, where descending motions larger than +0.03 hPa s-1 can be observed at the UTCV's center (12°S, 27°W), extending toward the ENE. Rising motions were found to the north of NEB, over the Maranhão State coast and not exceeding - 0.08 hPa s-1. These speeds are considered high for the 200 hPa level. Fig. 1(b) shows the OLR for the same month. It can be seen a loss of about 270 Wm-2 to the east of 35ºW related to the clear sky at the UTCV 's center. The minimum OLR values (between180 Wm-2 and 160 Wm-2) located over the left flank of the UTCV is associated with the SHFS and has an orientation in the NW-SE direction, crossing the coastline over Espírito Santo State (18°S). The large rainfall totals in Alagoas State, as well as in a major part of the NEB, occurred from January 12th to 20th. The left side of the vortex (SHFS) was over most of the region, along the coastline where the demographic density is high.

The omega vertical cross section along 30ºW and from 40ºS to 10ºN (Fig. 2(a)) revealed descending motions of +0.05hPa.s-1 between 7°S and 22ºS associated with the high pressure area in the polar side of the SHFS. The vortex center was over the Atlantic (about 8°S, 25°W), as it can be noted in the OLR field (Fig. 1(b)) and satellite image (Fig. 5(b)). Ascending motions to south of the center (20ºS-40ºS) were associated with the low pressure area of the extratropical cyclone, a part of the SHFS that generated the UTCV. The convective activity on the left side of the UTCV was between 7ºS and 5ºN with low levels moisture convergence and upper levels divergence. There were not significant changes between Fig. 2(b) (January 20th) and the previous one, except for the waning rising motions, thus reflecting a decrease, though short- lived, in the convection.

The OLR flux over the entire NEB on January 18th (Fig. 3(a)) was relatively lower than its monthly mean (Fig. 1(b)). The fluxes over the ENE were found to be about 200 Wm-2, indicating cold cloud tops and intense rainfall. Two days later (Fig. 3(b)), the center of the UTCV shifted westward, with its left side over Alagoas State, where the fluxes decreased 20 to 40 Wm-2. This reduction was associated with an increase in convective activity, with high cloud tops and rainfall. It was observed that the positioning of the SHFS was clearly bounded by the 140 and 180 Wm-2 isolines, which correspond to temperatures between 220 K and 240 K, that is, cloud tops between about 9 and 11 km high. The SHFS orientation was NW - SE reaching the Atlantic Ocean.



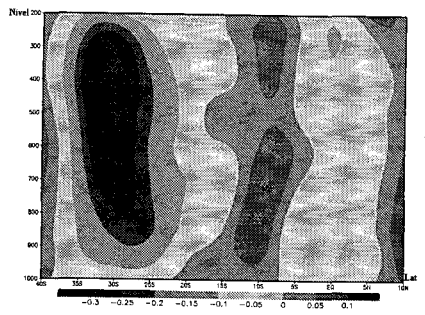
(a)



(b)

그림 1. 2004년 1월, (a) 200hPa에서 연직속도의 평균장과 (b) 장파 복사에너지의 평균장.

Fig. 1 Average fields for January, 2004 of: (a) 200 hPa vertical velocity (hPas-1) and (b) Outgoing Longwave Radiation (Wm-2).



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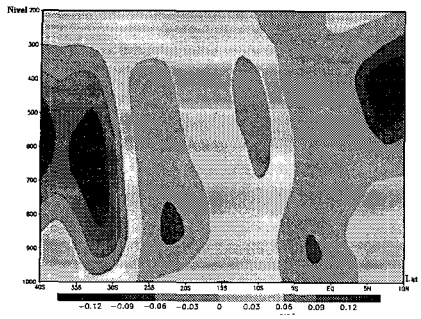
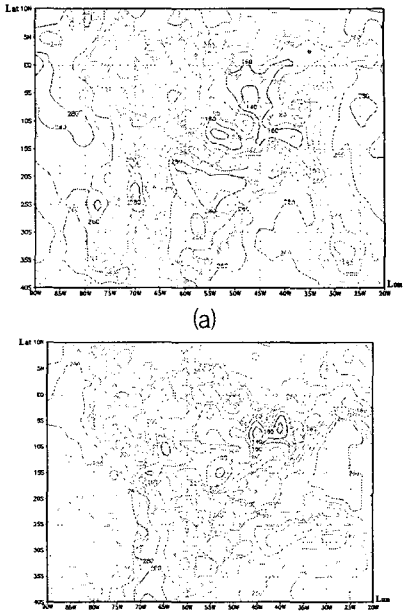


(b)

그림 2. 30°W에서 10°N-40°S를 지나는 연직속도의 연직분포 (a) 2004년 1월 18일, (b) 2004년 1월 20일.
Fig. 2 Omega cross section (hPa.s-1) along 30°W, and between 10°N-40°S, for (a) January18th and (b) January 20th, 2004.

These analyses were consistent with the 850 and 200 hPa divergence fields for January 18th, 2004, as shown in Fig. 4. Low level convergence (divergence) is associated with rising (descending) motions. A large area with meridian extension was seen spanning from the northern part of Minas Gerais state as far as up the coast of Piaui state (Fig. 4(a)) showing convergence and rising motion at 850 hPa level. The pattern shown in Fig. 4(b) was also consistent with divergence in the upper levels. However, the core of divergence was shifted southeastward with respect to its position in lower levels, over the southern coast of Bahia, thus indicating that rising motion were more vigorous over the continent.

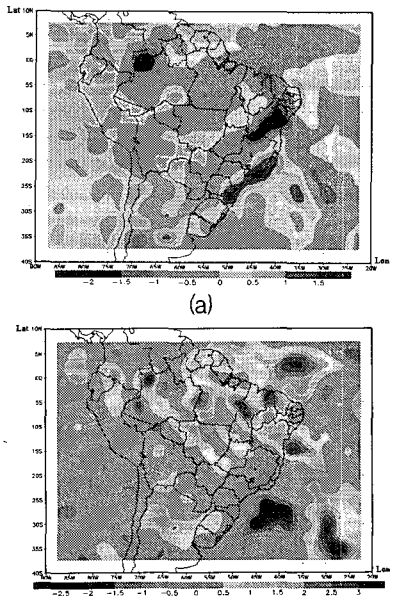
Radar images obtained with the weather radar of SIRMAL and GOES images (CPTEC/INPE) are shown in Fig. 5(a) and 5(b), respectively, for January 18th, at about 1500 LST. The core of the UTCV, with relatively weaker descending motion, was far off the coast (8°S, 25°W), as indicated by the omega motion and OLR analyses depicted in Fig.1. However, the left side of the UTCV, the SHFS itself, was over the continent and later extended southeastern towards the ocean. The convective activity, as seen by the corresponding cloudiness over the ENE, was responsible for intense rainfall from Sergipe to Pernambuco states (Fig. 5(a)) with its rainiest band coinciding with the more intense cloudiness visible in the water vapor channel of GOES image (Fig. 5(b)). The brown to green colors in the radar display represent gradually decreasing rainfall rates. Rates exceeded 136 mm hr-1 at 35.5°W, 10.2°S.



(a)

(b)

그림 3. 장파 복사에너지의 평균장 (a) 2004년 1월 18일, (b) 2004년 1월 20일.
Fig. 3 Mean charts of Outgoing Longwave Radiation (Wm-2) for January (a) 18th and (b) 20th, 2004.

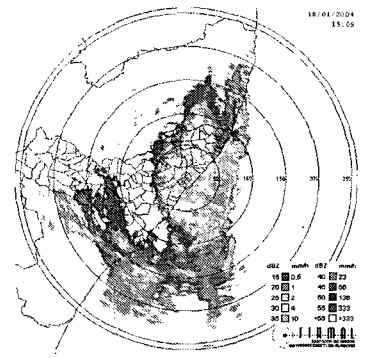


(a)

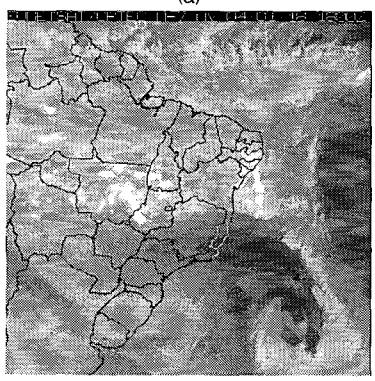
(b)

그림 4. 평균 발산장 (a) 2004년 1월 18일, (b) 2004년 1월 20일.
Fig. 4 Average divergence fields (10-5s-1) for January 18th, 2004: (a) at 850hPa and (b) at 200hPa levels.

The rains that hit the Sertão and Agreste zones of Alagoas state on January 20th (Fig. 6(a)), due to westward displacement of the UTCV, originated from cells exceeding 136 mm hr-1. An inter-comparison of the radar images (Fig. 5(a) and 6(a)) revealed that the areas with heavy rainfall decreased from one day to the next. A plausible explanation for this is either the vortex center, associated with anticyclonic divergent and descending motion, approached the continent or there was advection of relatively drier air into the convective region. Also, it possible that the trade winds weakened, thus reducing the moisture flux convergence and the area of the convective activity. The infrared GOES image (Fig. 6(b)) for 1900 LST clearly shows the border of the UTCV bent toward inland.



(a)



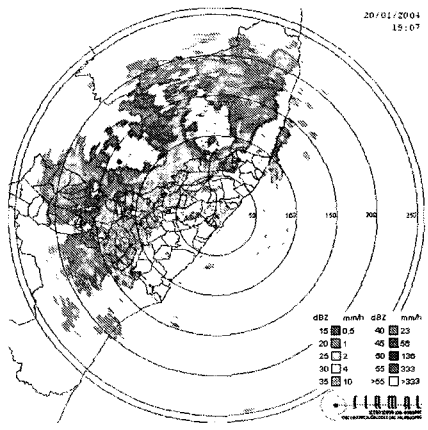
(b)

그림 5. (a) 2004년 1월 18일 15:00 LT의 기상 radar 영상(SIRMAL), (b) 2004년 1월 18일 GOES 수증기 영상(CPTEC/INPE).

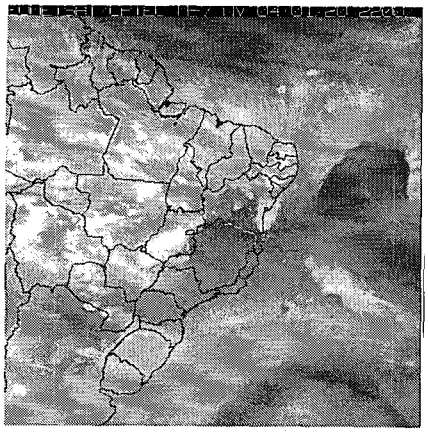
Fig. 5 On January 18th (a) SIRMAL weather radar image, at 15:05 LT and (b) GOES water vapor channel image at 15:00 LT (CPTEC/INPE).

The rainfall totals for January, 2004 and the corresponding climatic values for different mesoclimatic zones of Alagoas state are shown in Fig. 7. The positive anomalies are quite impressive, reaching values up to 12 times the long-term averages for some areas. Fig. 7(a) shows three stations in the Agreste region: Lagoa da Canoa, Limoeiro de Anadia and Mar Vermelho. In Lagoa da Canoa, the long-term average is 37 mm and in January 2004 the recorded rainfall was 371 mm (1000% increase). The Zona da Mata, the sugarcane cultivation zone (Fig. 7(b)), rain data were recorded in 6 stations. Usina Serra Grande, located in São Jose da Laje, for example, the rain total exceeded 400 mm against a long-term mean equal to 48 mm.

In the coastal zone (Litoral, Fig. 7(c)), Maceió recorded 265 mm, compared to its 57 mm mean. Fig. 7(d) presented the Low São Francisco River zone (Baixo S. Francisco) precipitation, in Marituba Distillery, located in Igreja Nova, the difference between January 2004 rain total and the mean was 490 mm. The Delmiro Gouveia gage, in the Sertão zone (Fig. 7(e)), for example, recorded a rain total 6 fold its monthly mean; in Pão de Açúcar (Sertão do São Francisco), whose long-term mean is 35mm, had a rainfall total of 446 mm (Fig. 7(f)). This town, on São Francisco River banks, had one of the worst floods of its history. Most of the houses near the river were submersed.



(a)



(b)

그림 6. (a) 2004년 1월 20일 15:00 LT의 기상 radar 영상(SIRMAL), (b) 2004년 1월 18일 GOES 수증기 영상(CPTEC/INPE).

Fig. 6 On January 20th (a) SIRMAL weather radar image, at 15:05 LT and (b) GOES water vapor channel image at 15:00 LT (CPTEC/INPE).

V. FINAL CONSIDERATIONS

The above than normal rainfall totals recorded in January 2004 were produced by an Upper Troposphere Cyclonic Vortex (UTCV) over NEB. Consequent floods left more than 46,000 people homeless and losses over US$10 million worth of material losses, only in Alagoas state. UTCVs occur more frequently in January, which is the peak of the NH winter. Apparently, they are more likely to occur in La Niña years or when the SSTs of the equatorial Pacific Ocean are close to their mean values. They occurred in five out of the six years in 1999-2004 periods.

Molion and Bernardo (2002) using ENSO Multivariated Indices (MEI) time series concluded that the 1950 - 1976 period was characterized by a predominance of La Niña events, coinciding with the negative phase of the Pacific Decadal Oscillation (PDO). On the other hand, intense El Niños were more frequent during 1977 - 1998, when the PDO was in its positive phase. When PDO is in its negative phase, the low pressure system of Aleutian Isles (northern Pacific) grows more intense and the equator to pole pressure gradient weakens in the north hemisphere. Weaker equator to pole seems to be one of the conditions for deep penetration of NHFS in equatorial latitudes and the appearance of UTCVs. Apparently, PDO is entering a new negative phase, thus UTCV frequency is apt to increase over NEB within the next 20 - 25 years, if the hypothesis is correct.

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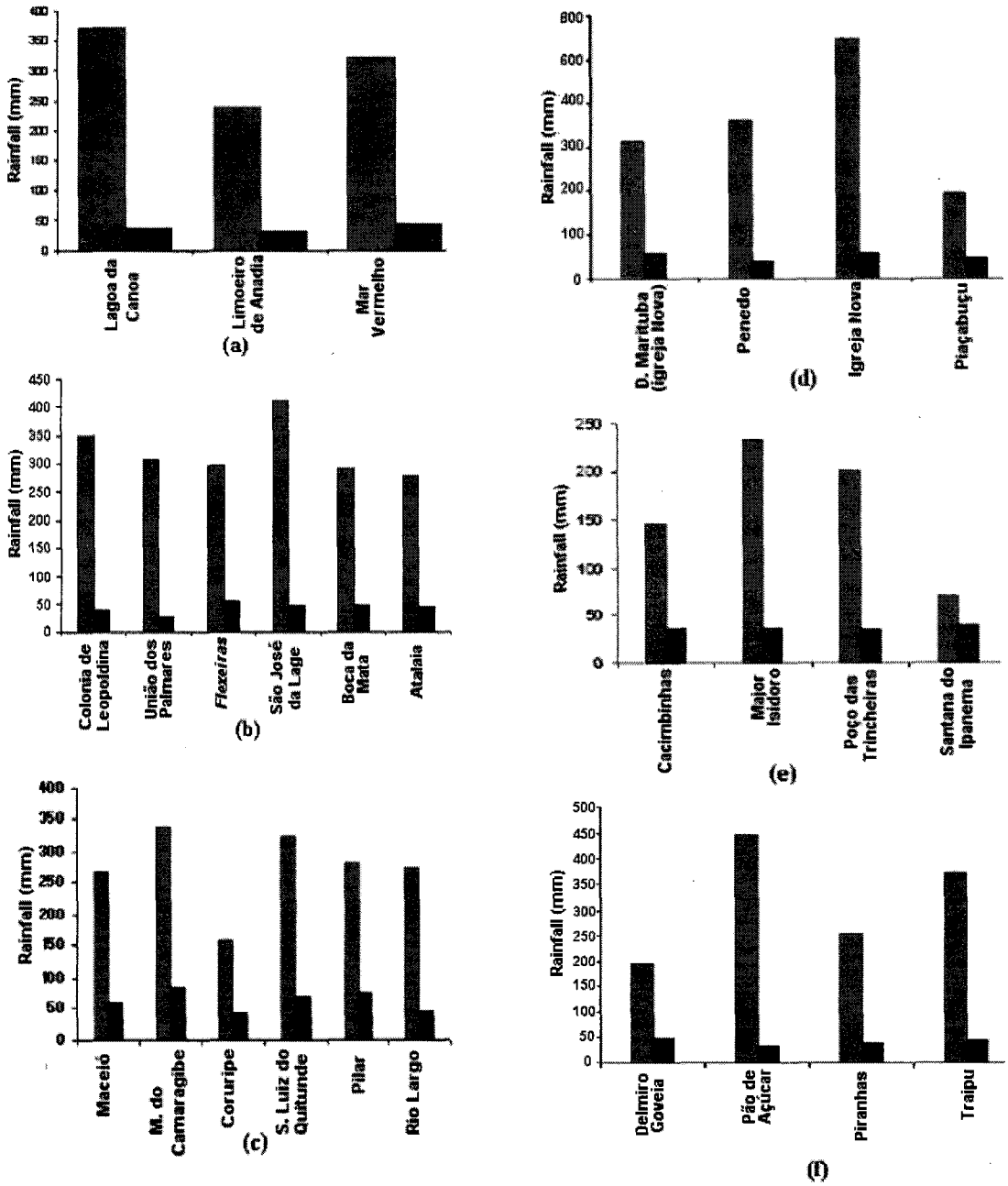

그림 7. 알라고아스주의 중규모 기후 지역에서 관측된 2004년 1월 총 강수량 (a) Agreste, (b) Zona da Mata, (c) Litoral, (d) Baixo São Francisco, (e) Sertão and (f) Sertão do São Francisco.

Fig.7 January 2004 rain totals (in grey) compared to long-term means (in black) for 6 mesoclimatic zones of State of Alagoas: (a) Agreste, (b) Zona da Mata, (c) Litoral, (d) Baixo São Francisco, (e) Sertão and (f) Sertão do São Francisco.

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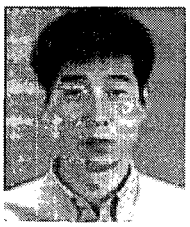

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