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# A climatological study of convective cloudbands in northeastern Brazil Part I: preliminary analysis

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**This work analyses the role of convective cloudbands (CCBs), associated with low-level convergence zones on the northeast region of Brazil (NE). A preliminary analysis of synoptic situations based on six years of meteorological satellite images and observed rainfall data for the region is presented. The results show two main patterns of CCBs. The first one classified as type A has a NW-SE orientation. It is associated with convergence zones due to cyclonic vortices or fronts, both rain-producing systems that reach mainly the southern, central and western regions of the NE. The second pattern (type S) results from interactions between frontal systems and upper-level cyclonic vortices over the Atlantic Ocean, to the east of the NE, as well as with the intertropical convergence zone (ITCZ). These frontal systems or convergence zones move northeastward and remain semistationary over the southeast coast of Brazil. The north-south orientation of these CCBs seems to be responsible for above average rainfall over the western and central parts of the NE. The type A cases are observed more frequently in October and November, while the type S cases are common in January, February and March. December is considered to be a transition month.**

## Introduction

Rainfall is the most important meteorological variable in determining the climate of tropical regions such as the northeast of Brazil region (NE). This region (Fig. 1) has an area of 8,462,871 km$^2$ and represents 18.2 per cent of the total area of Brazil. Annual average rainfall in the NE is not uniform, ranging from 1000 mm or more in the western and coastal regions to less than 400 mm in the hinterlands. The climate of the NE has been extensively studied by many researchers (e.g. Strang 1972; Ratisbona 1976; Kousky 1979; Chu 1983; Rao and Marques 1984; Rao et al. 1993) in recent decades.

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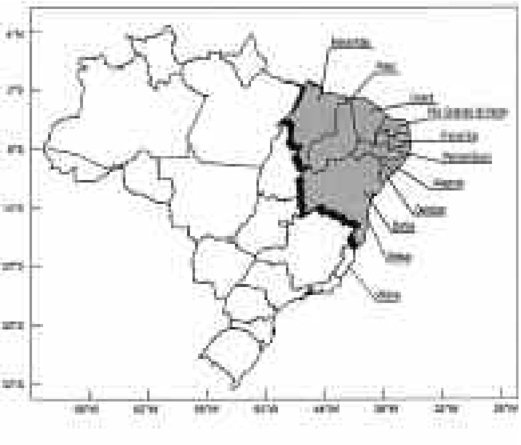
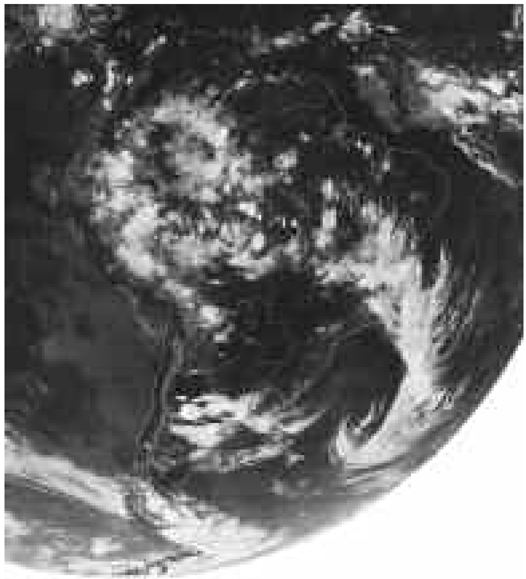
**Fig. 1** Schematic map of Brazil with the NE region shaded. The States, Vitória and Ilhéus, are locations used in the text as references for the classification of cloudbands.



The understanding of several types of rainfall-producing systems in the NE is of great social and economic interest; the main rationale being the potential for predictability. One such system, which brings rainfall to the southern and western regions of the NE, is an organised convective cloudband (CCB). This feature occurs during the austral spring and summer and is associated with frontal systems or convergence zones such as the South Atlantic convergence zone (SACZ) (Taljaard 1972; Kodama 1992). Also, during the austral summer, high-level tropospheric cyclonic vortices (HLTCVs) are often observed in the NE (Dean 1971; Kousky and Gan 1981; Ramirez et al. 1999), with more conspicuous effects in the southern, eastern and central regions of the NE. Kousky and Gan noticed S-shaped cloud patterns over the NE, which result from the interaction between fronts and HLTCVs. Using a seven-year climatology, Kousky and Gan (1986) concluded that the highest frequency of these cyclonic vortices occurs in January and February. Oliveira (1986) observed Y-shaped cloud patterns over the Amazon region, also associated with interactions between fronts and vortices (see Fig. 2). The role of these cloud patterns on the climate of the NE is still not thoroughly understood. In this work, several cases of cloud patterns over the NE were identified through visual analysis of satellite images, but they were not necessarily associated with the SACZ. Therefore, we have adopted the acronym CCB, reserving the term SACZ only when specific references are made to this system.

**Fig. 2** GOES infrared pictures showing examples of organised convective cloudbands (CCB) over the NE: (a) NW-SE orientation cloud pattern, 27 November 1981, 0117 UTC and (b) Y-shaped cloud pattern, 19 March 1983, 0017 UTC.

(a)



(b)

The main objective of this work is to study the influence of CCBs on the rainfall regime of the NE. In this sense, we will focus on the period of occurrence of CCBs in certain areas and on their interactions with HLTCVs. In order to accomplish this, a satellite-based analysis of meteorological events is presented in which CCBs have an influence on the precipitation regime of the NE. The synoptic characteristics of the interaction between CCBs and the convective activity in the NE will be discussed through case studies in a second part of this paper.

## Data analysis

Images from the Geostationary Operational Environmental Satellites (GOES), available at the Brazilian National Institute for Space Research (INPE), were used to construct the climatology for the study. They comprise three-hourly infrared images (0000, 0300,..., 2100 UTC) for the January 1980 to December 1983 period, and the visible images at 1500 UTC for the January 1980 to December 1983 and January 1987 to December 1988 periods. GOES-W data were used when GOES-E imagery was unavailable. The satellite images span a six-year period and the climatology of CCB events in any area of the NE was elaborated through a subjective analysis performed on the images.

A preliminary climatology based on visual analysis of the images for six years (1980, 81, 82, 83, 87 and 88) was carried out to study the frequency of occurrence, seasonal variability and spatial distribution of the observed events of organised CCBs. All the cases in which the NE showed CCB events were tallied. Images for 1984, 85 and 86 were not used because the position of the satellite was not favourable for the identification of CCB events over the Atlantic Ocean. A time series of only six years is a very short period from which to draw conclusions on CCB frequency of occurrence and seasonal variability. However, this analysis, which requires the manipulation of a large number of satellite pictures, enables insights into the behaviour of these weather systems.

The CCBs are usually organised by frontal systems. They are recognisable in an infrared image by a series of cumulonimbus of assorted size which organise themselves along lines, showing cold tops and clear-cut, well-defined round borders, where cirrus clouds are not present. The subjective criterion used in this work to detect and classify the CCBs over the NE is based on the visual observation of daily images from the GOES satellite. In particular, over Brazil, these bands show a typical northwest-southeast orientation. Only the systems with a well-defined synoptic-scale convective cloud pattern were included in the analysis. In a given latitudinal band, a CCB will be considered an event only if it has a lifetime of at least one day, and remains in the latitudinal band during the ensuing hours. The total incidence of CCBs in a given latitudinal band was used later to classify them according to the shape of the cloudband.

Situations where cyclonic vortices were responsible for organising the tropical convection were also noted. The influence of the observed systems on the monthly rainfall cycle was analysed through six years of monthly-averaged rainfall fields for November, December, January, February and March, using datasets from the Brazilian National Institute of Meteorology (INMET ) available at 75 sites.

Latitudinal cloudbands were utilised to follow the displacements of convergence zones in satellite pictures. These bands were defined by the latitude of the eastern coast of the continent where the CCBs are located, and were considered only when the (cloud) band reached the NE. Three bands were used: band 1, for latitudes south of 20°S, when the CCB is to the south of Vitória (Espírito Santo State); band 2, for latitudes between 20°S and 15°S, when the CCB is between Vitória and Ilhéus (Bahia State); and band 3, for latitudes north of 15°S, when the CCB is to the north of Ilhéus.

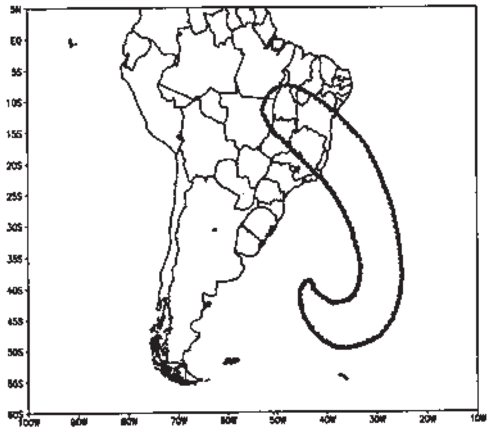
## Results

Two main configurations of CCBs were observed and classified as type A and type S, both schematised in Fig. 3. The type A cases are those in which the CCBs moved further northeast over the continent, reaching lower latitudes. They are oriented along the NW-SE direction, reaching, in most cases, the southern and western NE. It has been observed that in such cases tropical convection evolves either from frontal systems that penetrate into the tropics, or from low-level cyclogenesis over the southeastern NE. Apparently, there are no HLTCVs associated with type A events over the NE and adjoining regions, and they occur more frequently in the southern spring.

The type S pattern was described by Kousky and Gan (1981). In the current study, inspection of the six years of satellite data shows that the type S pattern evolves from a frontal system that has reached the southern NE and remains quasi-stationary, interacting with HLTCV cloud over the NE. The CCB has a north-south orientation, with the most intense convection observed over the western and the northern coast of the NE. Several cases of type Y configurations (Fig. 4), as described in Oliveira (1986), were also observed. In these cases, the CCB splits over central Brazil, with one branch over the Amazonian region, and the other over the NE, interacting with the HLTCV. These cases were classified as S type.

**Fig. 3 Typical configurations of CCB patterns over northeast Brazil: (a) type A and (b) type S.**

(a)



(b)

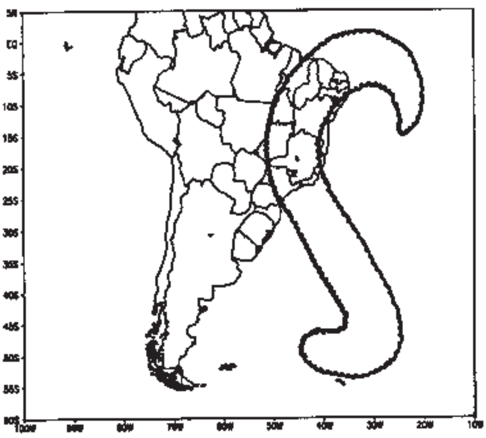
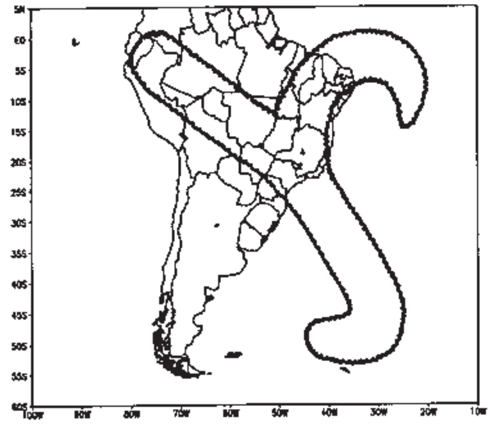


**Fig. 4 CCB over northeast Brazil: Y-shaped cloud pattern.**



Inspection of satellite pictures shows that quite frequently, CCBs interact with the cloud associated with the equatorial trough, causing rainfall in the northern NE. These cases were more frequent in the austral summer. Table 1 shows the number of observed cases of CCB types over the NE for each month and year, and their total number for the analysed period. It can be seen that October and November are the months most favourable for the formation of type A cases, while type S are more frequent in January, February and March. December seems to be a month of transition, during which cases of both types occur equally. Type S cases were not observed from May till October and type A cases were not reported for June and July.

Monthly averaged rainfall fields for six years were constructed to evaluate the influence of CCBs in the rainfall regime of the NE (Fig. 5). It can be seen that rainfall in November is more abundant in the southern and western regions of the NE, perhaps due to the occurrence of more type A events. From December on, an increased rainfall pattern of almost north-south orientation was observed over the western NE, probably due to the increase in type S systems. High rainfall values were observed in the northern NE in March, possibly associated with the ITCZ, while a minimum in rainfall is noted in Bahia State. The NE-SW orientation of the isohyets in the western NE stems apparently from the interaction between CCBs and the ITCZ, whose effects in the NE are more pronounced in March.

The more meridional high-level flow over continental South America during the austral summer, the quasi-permanent presence of an upper-level anticyclonic circulation and the associated downstream trough over the NE seem to combine in forming type S cases. As suggested by Kousky and Gan (1981), the simultaneous intensification of an upper-level ridge and the associated downstream trough seem to be instrumental in the formation of high-level cyclonic vortices.

There was not a single case of formation of CCBs over the NE during February, 1981 (Table 1); this month was extremely dry for the region (Kousky et al. 1983). On the other hand, rainfall was above average in the southern NE in January 1983, a year with a very intense El Niño as reported by Kayano et al. (1988), which might have favoured the frequent formation of the observed type A cases.

**Fig. 5** **Monthly mean rainfall (mm) over the NE for the period 1980, 81, 82, 83, 87 and 88: (a) November, (b) December, (c) January, (d) February and (e) March.**

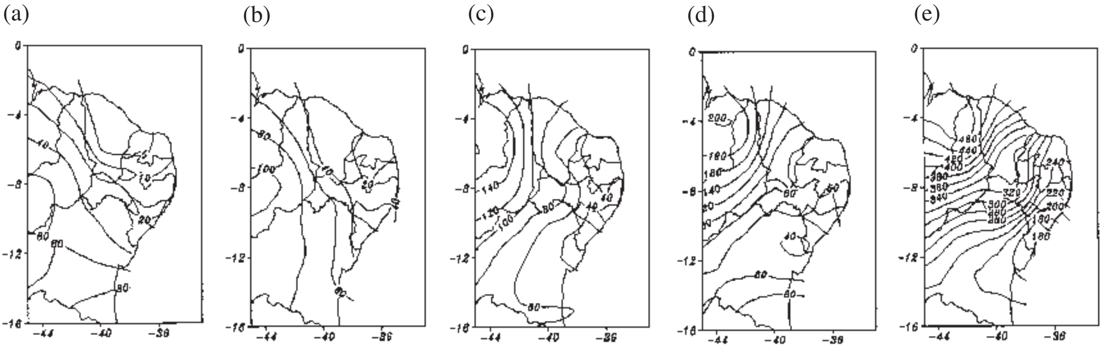



**Table 1.** **Observed cases of CCBs over the NE during the study period. Each letter (S or A) represents the occurrence of one case of that CCB type.**

| *Month/year* | *1980* | *1981* | *1982* | *1983* | *1987* | *1988* | *Total (A)* | *Total (S)* |
|---|---|---|---|---|---|---|---|---|
| JAN | SSA | SSS | SAAS | ASAA | SS | SA | 7 | 11 |
| FEB | ASA | | SSS | SS | SS | SSSS | 2 | 12 |
| MAR | S | AS | SS | SS | SS | SAA | 3 | 9 |
| APR | S | AA | AS | S | S | SSA | 4 | 6 |
| MAY | A | | AA | | | AA | 5 | 0 |
| JUN | | | | | | | 0 | 0 |
| JUL | | | | | | | 0 | 0 |
| AUG | | A | | | | | 1 | 0 |
| SEP | | | AA | | A | | 3 | 0 |
| OCT | A | AA | A | AAA | AA | AAAAAA | 15 | 0 |
| NOV | ASAA | SAAAA | AA | AAA | AAAAA | ASSA | 19 | 4 |
| DEC | AAS | SASA | AAS | ASS | AAAS | ASSS | 11 | 10 |
| TOTAL (A) | 10 | 12 | 12 | 10 | 11 | 15 | | |
| TOTAL (S) | 7 | 7 | 9 | 8 | 8 | 13 | | |
| TOTAL | 17 | 19 | 21 | 18 | 19 | 28 | | |

A subjective analysis of the intensity of the CCBs is given in Table 2. This analysis was based on cloud-top brightness temperature and the extension of the cloudiness area as observed in the satellite images. A general feature of the cases that occurred in the months with the least number of events was that they were also less intense. The type A cases (Table 2(a)) occur more frequently in the austral spring. It is worth noting that the southern part of the NE has a rainfall maximum centred in December, probably due to the influence of such systems.

Observationally, it was noted that in the cases where there was an interaction with the high tropospheric cyclonic vortices, the type S CCBs were further north over the NE than the type A systems, and most of the time, they also interacted with the ITCZ. The high tropospheric vortices occur predominantly in the January-February period that coincides with less rainfall in the northern NE. This is very suggestive of an inverse relationship between the occurrence of cyclonic vortices and rainfall in the southern NE. This result agrees with that obtained by Kousky and Gan (1981) who found that the westward shift of the cyclonic vortex increases convection over the northern NE and diminishes it over the southern and central NE.

Table 3(a) shows the number of type A cases that occurred in each latitudinal band. It also shows the number of cases that originated from the previous bands. It is important to note that the cases appearing in bands 2 and 3 do not imply the absence of organised CCBs in band 1, but rather an associated cloudiness over the NE. It can be seen that the majority of type A cases that crossed band 1 reached band 2, and that many of them also reached band 3.

Type S cases occur more frequently in the austral summer (Table 3(b)), being most frequent in

**Table 2. Intensity of CCB cases based upon cloud-top brightness temperatures and extension of the cloud area as observed in the satellite images: intense (I), medium (M) and weak (W): (a) type A cases, (b) type S cases.**

(a)

| *Month/year* | *1980* | *1981* | *1982* | *1983* | *1987* | *1988* | *Total I* | *Total M* | *Total W* |
|---|---|---|---|---|---|---|---|---|---|
| JAN | M | | MW | WMI | | M | 1 | 4 | 2 |
| FEB | IM | | | | | | 1 | 1 | 0 |
| MAR | | I | | | | IW | 2 | 0 | 1 |
| APR | | WM | M | | | M | 0 | 3 | 1 |
| MAY | W | | WW | | | WW | 0 | 0 | 5 |
| JUN | | | | | | | 0 | 0 | 0 |
| JUL | | | | | | | 0 | 0 | 0 |
| AUG | | W | | | | | 0 | 0 | 1 |
| SEP | | | WW | | M | | 0 | 1 | 2 |
| OCT | W | WW | W | WWW | WM | MIWWMM | 1 | 4 | 10 |
| NOV | WMM | MWWW | WW | WWW | WWIWI | IM | 3 | 4 | 12 |
| DEC | WM | WM | MW | W | MWM | I | 1 | 5 | 5 |

(b)

| *Month/year* | *1980* | *1981* | *1982* | *1983* | *1987* | *1988* | *Total I* | *Total M* | *Total W* |
|---|---|---|---|---|---|---|---|---|---|
| JAN | II | MII | IM | M | MM | M | 5 | 6 | 0 |
| FEB | M | | MMI | IM | MW | MIIM | 4 | 7 | 1 |
| MAR | I | I | WW | MI | MW | M | 3 | 3 | 3 |
| APR | W | | W | W | M | MI | 1 | 2 | 3 |
| MAY | | | | | | | 0 | 0 | 0 |
| JUN | | | | | | | 0 | 0 | 0 |
| JUL | | | | | | | 0 | 0 | 0 |
| AUG | | | | | | | 0 | 0 | 0 |
| SEP | | | | | | | 0 | 0 | 0 |
| OCT | | | | | | | 0 | 0 | 0 |
| NOV | M | W | | | | MW | 0 | 2 | 2 |
| DEC | I | WW | I | WW | I | MWW | 3 | 1 | 6 |

February. One of the characteristics of these systems is their persistence with few of the cases crossing band 1 reaching band 2. The northward displacement of the CCBs that reached band 2 was associated with a weakening of the high-tropospheric cyclonic vortices. It was also observed that there were situations where vortices could still be detected when the cloud-band was already in band 2.

The total number of cloudy days (inferred from satellite pictures) over the NE due to type A and S CCBs is shown in Fig. 6. Together, the type A and S CCBs account for December, January and February being the months with increasingly more cloudy days. The two most contrasting months are February and November. In February, 53 cloudy days were observed due to type S and only 13 due to type A cases, while in November there were 75 cloudy days for type A and only 11 for type S. On average, there were 12 cloudy days in November, with the cloudiness associated with type A cases. For the type-S cases, December, January, February and March have about 8.5 cloudy days per month.

The total number of cloudy days over the NE for each latitudinal band is shown in Fig. 7. The graphs show that the number of days with type A cases is evenly distributed in these three bands, while most of the cloudy days for the type-S cases occur when the CCB is in band 1. This is clearly seen in the months of highest frequency for type S cases. For October, it was noted that for the type-A cases there were 21, 23 and 10 days in bands 1, 2, and 3, respectively. The month of highest occurrence of type S cases was February, and of the 53 related days, 52 were associated with CCBs in band 1.

**Table 3. Number of CCB cases associated with cloudiness over the NE for each latitudinal band. (a) Type A cases, (b) type S cases. The band 2* column represents cases originating from band 1; band 3* cases originating from band 1 and 2; and band 3** represents cases coming from band 2.**

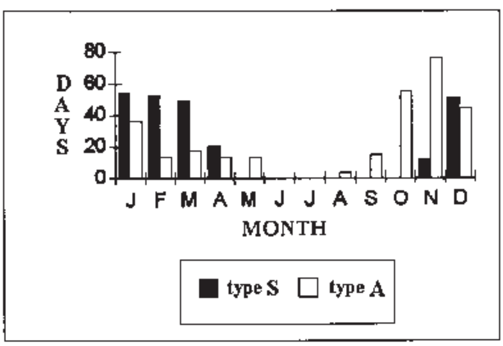
(a)

| *Month* | *Band 1* | *Band 2* | *Band 2** | *Band 3* | *Band 3** | *Band 3*** |
|---|---|---|---|---|---|---|
| JAN | 5 | 6 | 4 | 2 | 2 | 0 |
| FEB | 2 | 2 | 2 | 2 | 2 | 0 |
| MAR | 2 | 3 | 2 | 3 | 2 | 1 |
| APR | 2 | 3 | 2 | 3 | 1 | 1 |
| MAY | 4 | 5 | 4 | 1 | 0 | 1 |
| JUN | 0 | 0 | 0 | 0 | 0 | 0 |
| JUL | 0 | 0 | 0 | 0 | 0 | 0 |
| AUG | 1 | 1 | 1 | 1 | 1 | 0 |
| SEP | 0 | 2 | 0 | 2 | 0 | 2 |
| OCT | 12 | 12 | 9 | 6 | 4 | 2 |
| NOV | 11 | 19 | 11 | 5 | 3 | 2 |
| DEC | 7 | 9 | 5 | 2 | 0 | 2 |

(b)

| *Month* | *Band 1* | *Band 2* | *Band 2** | *Band 3* | *Band 3** | *Band 3*** |
|---|---|---|---|---|---|---|
| JAN | 10 | 4 | 4 | 1 | 1 | 0 |
| FEB | 12 | 1 | 1 | 0 | 0 | 0 |
| MAR | 9 | 5 | 5 | 2 | 2 | 0 |
| APR | 3 | 4 | 1 | 1 | 0 | 1 |
| MAY | 0 | 0 | 0 | 0 | 0 | 0 |
| JUN | 0 | 0 | 0 | 0 | 0 | 0 |
| JUL | 0 | 0 | 0 | 0 | 0 | 0 |
| AUG | 0 | 0 | 0 | 0 | 0 | 0 |
| SEP | 0 | 0 | 0 | 0 | 0 | 0 |
| OCT | 0 | 0 | 0 | 0 | 0 | 0 |
| NOV | 4 | 1 | 1 | 1 | 1 | 0 |
| DEC | 10 | 2 | 2 | 1 | 1 | 0 |

**Fig. 6 Total number of days with cloudiness over the NE during the study period, associated with type S and type A CCB patterns.**

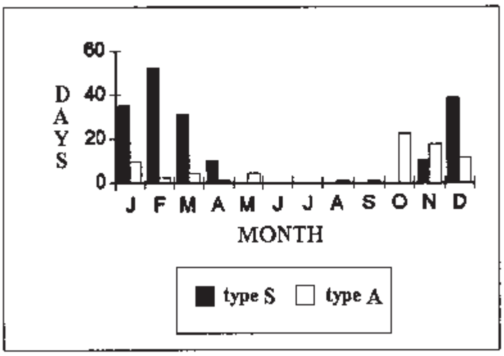



These events occur when convergence zones, such as the SACZ, remain semistationary over southeastern Brazil and interact with HLTCVs in the western Atlantic Ocean.

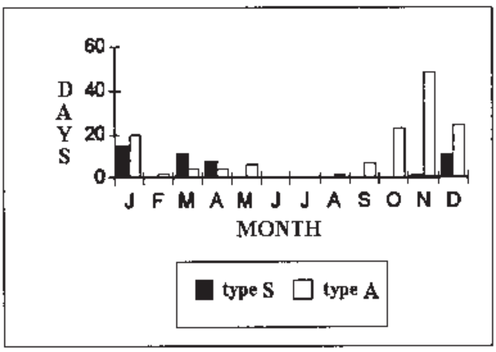
The monthly mean number of days with cloudiness over the NE for each latitudinal band is given in Table 4, which shows that the type A cases spend less time in band 1 than type-S cases. February was the preferred month for type S systems to be stationary in band 1, with few days observed in band 2, so that few of the analysed cases had a significant north-northeastern displacement. The type A cases that reached band 3 remained there for longer than in the previous two bands, which is in agreement with Oliveira (1986). During the southern winter, the monthly mean number of days of cloudiness for each CCB type over the NE is negligible.

**Fig. 7 Number of days with cloudiness associated with CCB patterns over the NE for: (a) band 1, for latitudes south of 20°S, when the CCB is to the south of Vitória (Espírito Santo State); (b) band 2, for latitudes between 20°S and 15°S, when the CCB is between Vitória and Ilhéus (Bahia State) and (c) band 3, for latitudes north of 15°S, when the CCB is to the north of Ilhéus.**

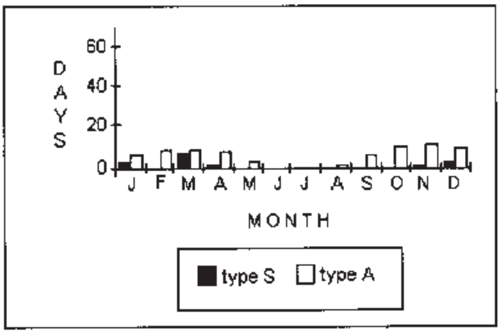
(a)




(b)




(c)




## Concluding remarks

This study focuses on the role of convective cloud-bands (CCBs), as observed from satellite images, on the climate of the northeast Region of Brazil (NE), with emphasis on the austral summer season. Two types of CCBs (classified as type A and type S) were inferred from a six-year climatology. The type A cases are those in which the CCBs have a NW-SE orientation and a northeastward displacement. They mainly reach the southern, central and western regions of the NE, causing rain episodes in these regions. The type S cases are those in which CCBs that originated from the South Atlantic convergence zone or midlatitude frontal systems, remain semistationary over the NE. The orientation of these CCBs is north-south, with significant influences on a longitudinally stretched band over the western and central parts of the NE. In these cases, we suggest that there could be an interaction with the upper-level cyclonic vortices cloudiness, over the Atlantic Ocean as well as with the ITCZ, mainly when this zone is found in its southernmost position. Type S cases were also responsible for above-average rainfall amounts. The type A cases were observed more frequently in October and November, while type S cases occur more frequently in January, February and March. December was a transition month, in which both types occur equally. No austral winter cases were observed. As the satellite data used in this study cover only a six-year period, the analysis presented should be considered as preliminary.

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**Table 4. Monthly mean number of days of cloudiness for each CCB type and latitudinal band (B1, B2 and B3).**

| *Band/month* | *Jan* | *Feb* | *Mar* | *Apr* | *May* | *Jun* | *Jul* | *Aug* | *Sep* | *Oct* | *Nov* | *Dec* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B1/A | 1,8 | 1,0 | 2,0 | 0,5 | 1,0 | 0 | 0 | 1,0 | 0 | 1,8 | 1,5 | 1,4 |
| B2/A | 3,3 | 1,0 | 1,3 | 1,3 | 1,2 | 0 | 0 | 1,0 | 3,5 | 1,9 | 2,5 | 2,7 |
| B3/A | 3,5 | 4,5 | 3,0 | 2,7 | 3,0 | 0 | 0 | 1,0 | 3,0 | 1,7 | 2,2 | 4,5 |
| B1/S | 3,5 | 4,3 | 3,4 | 3,3 | 0 | 0 | 0 | 0 | 0 | 0 | 2,3 | 3,7 |
| B2/S | 3,8 | 1,0 | 2,2 | 2,0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,0 | 5,5 |
| B3/S | 4,0 | 0 | 3,5 | 2,0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,0 | 2,0 |

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