

## Connection of the frontal extremities with intertropical convergence zone and analysis of associated phenomena.

### *Ligação da extremidade frontal com zona de convergência intertropical (zcit) e análise de fenômenos associados.*

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**Abstract:** The Intertropical Convergence Zone (ITCZ) and Frontal Extremities (FE) are the main systems producing heavy rain in the Brazilian Northeast (BNE). The simultaneous influence of both systems causes damage to society due to floods and landslides. The study aims are as follows: identification of the FE structure connected with ITCZ; elaboration of the atmospheric circulation pattern and analysis of the associated phenomena. Frontal identification was elaborated using potential equivalent temperature advection, relative vorticity and infrared satellite images. Five events showed connection of the frontal systems with ITCZ during the study period (2008-2017). Synoptic analysis of the tropospheric structure presented differences between cases of the frontal system connected with ITCZ and cases without such connection. Both patterns of the troposphere for the frontal zone connected with ITCZ and not connected were elaborated. This connection occurs when: Subtropical Jet Stream (SJS) is in the southwest of Brazil; anticyclonic circulation at the high levels is presented in the BNE [excluding event with High Tropospheric Cyclonic Vortex- (HTCV)]. The connection of ITCZ and FE does not happen when SJS and cyclonic circulation at the high levels is in the BNE. Humid mist and heavy rain were recorded in all ITCZ and FE connection cases. One of the cases (20-28/05/2017) with connection of the two systems caused heavy rain, 4 deaths and landslides in Alagoas.

**Keywords:** Frontal zone; Circulation patterns; BNE.

**Resumo:** A Zona de Convergência Intertropical (ZCIT) e as Extremidades Frontais (EF) são os principais sistemas produtores de chuvas intensas no Nordeste brasileiro (NEB). A influência simultânea de ambos os sistemas causa prejuízos à sociedade devido a enchentes e deslizamentos de terra. Os objetivos do estudo são os seguintes: identificação da estrutura EF ligada ao ZCIT; elaboração do padrão de circulação atmosférica e análise dos fenômenos associados. A identificação frontal foi elaborada usando advecção de temperatura potencial equivalente, vorticidade relativa e imagens de satélite infravermelho. Cinco eventos mostraram conexão dos sistemas frontais com ZCIT durante o período de estudo (2008-2017). A análise sinótica da estrutura troposférica apresentou diferenças entre os casos do sistema frontal conectado com ZCIT e os casos sem tal conexão. Ambos os padrões da troposfera para a zona frontal conectada com ZCIT e não conectada foram elaborados. Esta conexão ocorre quando: Corrente de Jato Subtropical (CJS) está no sudoeste do Brasil; circulação anticiclônica em altos níveis é apresentada no NEB [excluindo evento com Vórtice Ciclônico de Altos Níveis (VCAN)]. A ligação da ZCIT e EF não acontece quando: está presente CJS e circulação ciclônica em altos níveis no NEB. Em todos os casos que apresentaram ligação da ZCIT com EF foram registradas as ocorrências de Névoa úmida e chuva forte. Um dos casos (20-28/05/2017) com ligação dos dois sistemas causaram chuva forte, deslizamentos de terra e 4 mortes em Alagoas.

**Palavras-chave:** Zona frontal; Padrões de circulação; NEB.

## 1. Introduction

Agriculture and livestock are the economic base of the State of Alagoas (Northeast Brazil), and productivity depends on the distribution and frequency of rainfall (MARQUES, 2008, p.22).

Three regions with different types of precipitation regime in Northeast Brazil (NEB) are described (STRANG, 1972; MOLION & BERNARDO 2002): 1) northern region with wet period between February and May, 2) southern region with wet period between months from November to February and 3) coastal region with the rainy season from April to July.

The main rain-forming systems in the northern region are the Intertropical Convergence Zone (ITCZ), breezes and Wave Disturbance in the Trade Winds (POA) (HASTENRATH & HELLER, 1977; CITEAU et al. 1988; UVO 1989; MOLION & BERNARDO, 2002). The stationary frontal system is the main precipitation formation system in the southern region (ANDRADE, 2007). Precipitation in the coastal region is due to the circulation of the sea breeze (KOUSKY, 1979), High Level Cyclone Vortex (VCAN) (KOUSKY & GAN, 1981) and front end (GEMIACKI, 2005, CRUZ, 2008).

The main period of rain on the east coast of the Northeast is concentrated between the months of May and August, with the ends of frontal systems being one of the main meteorological systems active during this time of year (PONTES DA SILVA et al., 2011).

The position and intensity of the Intertropical Convergence Zone (ITCZ) in the Equatorial Atlantic Ocean is extremely important in determining the quality of the rainy season in the semiarid region of the Northeast. Researches carried out show the effect of oceanic and atmospheric conditions that modulate the seasonal variability of the ZCIT and its relationship with rainfall over northern Northeastern Brazil (HASTENRATH & HELLER, 1977; HASTENRATH, 1984; & XAVIER et al., 2000). The main characteristic of this system is to position itself over oceanic areas with positive Sea Surface Temperature (SST) anomalies and negative Sea Level Pressure (PNM) anomalies (HASTENRATH, 1991).

ZCIT sometimes tends to move a little further south or north of its climatological position, as observed in El Niño (La Niña) years, where the associated convective band tends to move a little more towards north or south (COELHO et al., 2004). Moura and Shukla (1981) suggested that Sea Surface Temperatures (SST) variation is the main factor in ITCZ variation, when temperatures in the South Atlantic are warmer (positive) in relation to the North Atlantic (negative), a ZCIT tends to move to the south and the inverse of the ZCIT tends to move to the north, contributing to rainy or dry years in the NEB, called Atlantic dipole.

The land-sea interaction is of great importance to understand the position of the ZCIT to the north and south of the equator. Several physical variables are used to locate fluctuations in the average ZCIT positioning (MOURA & SHUKLA, 1981).

Cold fronts affect South America throughout the year (KOUSKY, 1979). Cold fronts can be identified through satellite images along with operational atmospheric models, taking into account the wind's turn to the south, the southerly wind persistence for at least one day, and an air temperature drop simultaneous to the wind's turn. Wind or even two days later (RODRIGUES et al., 2004). During the passage of a cold front, there is an increase in pressure, a sudden drop in temperature, an increase in the strength of the wind, a variation in its direction.

The need to identify the frontal zone is associated with the occurrence of precipitation in this frontal zone. Precipitation formation processes in the NEB were summarized by MOLION and BERNARDO (2002), where the authors present evidence of the occurrence of intense precipitation in the frontal zones. An association of synoptic and mesoscale systems with intensive precipitation was studied by PONTES DA SILVA et al. (2011) and during their study found that the Frontal Zones are among the most important systems that produce precipitation in NEB. Given this, the identification of the frontal zone in the tropical region is difficult in operational practice. A frontal structure in this region is different than in the extratropical region and therefore a traditional frontal identification method is not accurate. FEDOROVA et al.,

The destruction of property and human lives caused by heavy rains in the NEB causes disturbances in the region's populations (MARQUES, 2010), mainly due to floods and landslides. A practical way to alleviate the effect of this problem is to be aware of the systems that produce intense precipitation and, from there, develop methods that can predict the formation of the processes that give rise to those systems. This is not an easy task, as the northeast region of Brazil, which includes Alagoas, is located in an area where tropical processes interact with mid-latitude processes, making it difficult to identify the systems, which combined can generate intense rainfall (PONTES DA SILVA et al., 2011).

The objective of this work is to identify the structure of frontal systems that are linked to the Intertropical Convergence Zone (ITCZ) in the NEB from 2008 to 2017, to elaborate a pattern of atmospheric circulation and to analyze the associated phenomena.

## 2. Methodology

The study area of this work is the Northeast region located between the geographic coordinates: Latitude 17.5°S and 2°S and Longitude 48°W and 35°W, (Figure 1).

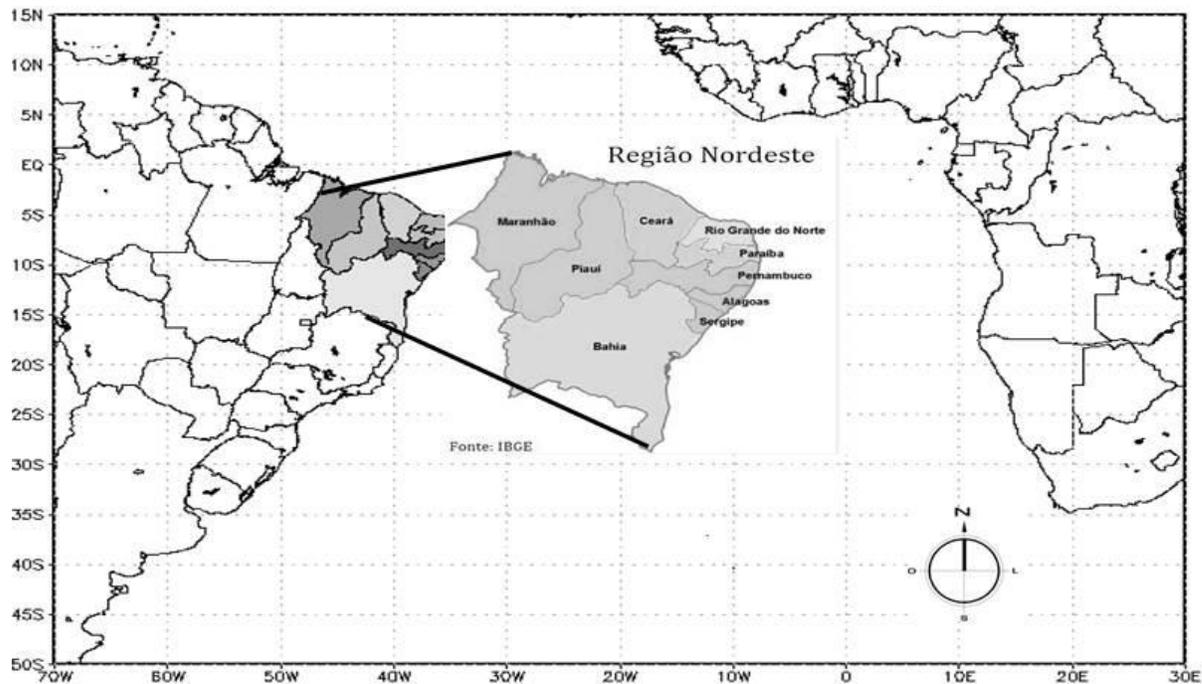


Figure 1 – Characterization of the study region.

Source: Adapted from IBGE (2009).

### 2.1. Data used to identify cold fronts and ZCIT

The Climanalise database was used to identify frontal systems until 2014, available at <http://climanalise.cptec.inpe.br/~rclimanl/boletim/>.

The analysis of cloudiness associated with the frontal zone and the position of the ZCIT was elaborated using images from the geostationary satellite GOES and METEOSAT, from the Infrared (IR) channel; in the image database of the Division of Satellites and Environmental Systems (DSA) from 2008 to 2017 made available by CPTEC/INPE.

Data from the reanalysis of the European Center of Medium Range Weather Forecast (ECMWF) with spatial resolution  $0.125^\circ \times 0.125^\circ$  and temporal resolution of 06h, obtained through the website <http://www.ecmwf.int/>, were used to obtain the data. meteorological fields, in a domain of  $50^\circ\text{S} - 15^\circ\text{N}$  and  $70^\circ\text{W} - 30^\circ\text{E}$ , for the events found in the study period (2008 to 2017).

The variables considered were the Pressure at Mean Sea Level (MNP), the zonal (u) and meridional (v) wind components, air temperature and relative humidity, at the levels of 1000 hPa, 500 hPa and 200 hPa. Derived fields were generated, such as PNM, relative vorticity, current lines and isotacs, equivalent potential temperature advection, which were visualized using the Grid Analysis and Display System (GrADS) software.

### 2.2. Identification of cold fronts

### 2.3. Frontal identification by operational analysis

The location of the frontal zone was identified by the method used in the synoptic operational practices. This zone is determined as follows: (1) "elongated" zone in a baroclinic cyclone trough (by pressure maps at surface level) and cyclonic vorticity (at the level of 1000 hPa), (2) confluence zone current lines at low levels (925 and 850 hPa), (3) located between

regions with hot and cold air advection (925 and 850 hPa levels (PETTERSEN, 1956, BLUESTEIN, 1993, FEDOROVA, 1999; FEDOROVA & CARVALHO), 2000, FEDOROVA et al, 2016). (4) "strong" temperature gradient is generally significant in order of magnitude or greater than the typical synoptic scale strength of 10 K per 1000 km<sup>-1</sup> (or 10g kg<sup>-1</sup> water vapor mixing rate per 1000 km) (BLUESTEIN, 1993). In the frontal zone "the temperature" changes drastically in the horizontal direction by an average of 3°C in the subtropics and 4-5°C in the midlatitudes and in the polar regions as defined by TALJAARD (1972). These systems were analyzed from their formation, during the entire period of displacement until reaching the region of interest and whether or not they were linked to ZCIT.

### 2.3.1. Front identification using equivalent potential temperature

The equivalent potential temperature and its advection were calculated to analyze the distribution and horizontal variation in the region, this methodology was previously used by Germiacki (2005) and Fedorova (2016), they observed that the equivalent potential temperature variation in the frontal zone (ZF) was satisfactory in the NEB region. Therefore, a horizontal distribution of the advection of ( $\theta_e$ ) was used for frontal identification. These parameters were calculated by the following equations (BOLTON 1980) cited by Fedorova et al., (2016).

$$\theta_e = T_k \left( \frac{1000}{p} \right)^{0.2854(1-0.28 \cdot 10^{-3}r)} \exp \left[ \frac{3.267}{T_{lcl}} - 0.00254r(1+0.81 \cdot 10^{-3}r) \right] \quad (1)$$

where TK is the absolute temperature (K), p atmospheric pressure, r mixing ratio at the initial level (g kg<sup>-1</sup>), T<sub>lcl</sub> the absolute temperature at the lifting condensation level (K), calculated by the equation:

$$T_{lcl} = \frac{1}{\frac{1}{T_d - 56} + \frac{\ln(T_k - T_d)}{800}} + 56, \quad (2)$$

$$\text{Adv}\theta_e \equiv -V_H \cdot \nabla_H \theta_e = - \left( u \frac{\partial \theta_e}{\partial x} + v \frac{\partial \theta_e}{\partial y} \right), \quad (3)$$

where x and y are the wind components (m / s).

A heat wave on maps of  $\theta_e$  (K) ahead of the ZF and a cold wave of  $\theta_e$  (K) with a high gradient behind it have been used as criteria for ZF identification. Furthermore, ZFs were observed between the positive values of Adv $\theta_e$  in front of the ZF and the negative values of Adv $\theta_e$  behind it.

### 2.3 Identification of the front end (EF) connections with the Intertropical Convergence Zone (ITCZ)

In order to identify the link between the EF and the ZCIT, the following characteristics were analyzed: 1) In the satellite image, the connection of the cloud band associated with the EF and the ZCIT in the NEB region was observed.

2) In the vorticity field, negative values of relative vorticity were observed in the cyclone, cyclone trough and in the ZCIT, at the time when the cloudiness band was observed.

3) In the field of equivalent potential temperature advection the fronts were observed between the positive values of Adv $\theta_e$  in front of the ZF and the negative values of Adv $\theta_e$  behind the cyclone trough and in the ZCIT (FEDOROVA et al, 2016).

### 2.3.2. Analysis of associated adverse phenomena

### 2.3.3. Analysis of fog, wet fog and thunderstorm.

The analysis of fog, wet fog and thunderstorm was performed using METAR data from meteorological stations located in the East Coast of NEB, obtained from the website available at: [www.redemet.aer.mil.br](http://www.redemet.aer.mil.br).

### 2.5 Precipitation Analysis

For the precipitation analysis, high spatial-temporal resolution satellite precipitation estimation data (8 x 8 km every 30 min) from the (CMORPH) of the Climate Prediction Center (CPC) of the National Centers for Environmental Prediction

(NCEP) were used of the National Oceanic and Atmospheric Administration (NOAA), in the domain of 30°S to 10°N and 70°W to 20°W, available at:[ftp://ftp.cpc.ncep.noaa.gov](ftp://ftp.cpc.ncep.noaa.gov;);

### 3. Results and discussion

#### 3.1 The general analysis

During the study period analyzed (2008 to 2017), 27 frontal systems that reach the NEB region were registered. Of the 27 cases observed, only 5 cases show a link between EF and ZCIT. Among unconnected cases, 3 last for 2 days with the shortest duration recorded in all cases analyzed, 5 last for 4 days, 6 last for 5 days, 5 last for 6 days, 2 last for 7 days and 1 lasting 10 days with the longest duration recorded among the cases analyzed. Among the 5 cases with connection, 3 lasted for 4 days, the other two lasted for 5 and 7 days respectively (Table 1).

*Table 1 – Frontal zones that affected the NEB region for 10 years (2008-2017), duration of cold fronts and connection with ZCIT. N-no, Y-yes.*

| No. | START END             | DURATION | EF connection with ZCIT |
|-----|-----------------------|----------|-------------------------|
| 1   | 06/02/2008            | 2 days   | N                       |
| two | 11-20/09/2008         | 10 days  | N                       |
| 3   | 10/06/2008            | 5 days   | N                       |
| 4   | 12/06/2008            | 6 days   | N                       |
| 5   | 20-23/08/2009         | 4 days   | N                       |
| 6   | 07-10/04/2010         | 4 days   | s                       |
| 7   | 06/01/2010            | 2 days   | N                       |
| 8   | 12-18/08/2010         | 6 days   | N                       |
| 9   | 06/02/2011            | 4 days   | s                       |
| 10  | 09/01/2011            | 2 day    | N                       |
| 11  | 17-20/10/2011         | 4 days   | N                       |
| 12  | 24-29/09/2012         | 4 days   | N                       |
| 13  | 12-16/08/2013         | 5 days   | N                       |
| 14  | 10/05/2013            | 6 days   | N                       |
| 15  | 05/09/12/2014         | 4 days   | s                       |
| 16  | 037/09/2014           | 4 days   | N                       |
| 17  | 20-23/09/2014         | 4 days   | N                       |
| 18  | 02-6/10/2014          | 5 days   | N                       |
| 19  | 14-20/11/2014         | 7 days   | N                       |
| 20  | 04/29/2015 05/04/2015 | 5 days   | s                       |
| 21  | 12-17/05/2015         | 5 days   | N                       |
| 22  | 01-5/01/2016          | 5 days   | N                       |
| 23  | 03/28/2017 03/04/2017 | 7 days   | N                       |
| 24  | 16-22/05/2017         | 7 days   | s                       |
| 25  | 1-4/09/2017           | 6 days   | N                       |
| 26  | 10/31/2017 11-04/2017 | 5 days   | N                       |
| 27  | 10-16/11/2017         | 6 days   | N                       |

*Source: Author (2018).*

Table 2 shows the study period and seasons. It can be observed that most front episodes occur between the months of August, September and October, registering 13 cases. The summer season has the smallest number of cases, only 2. The

cases observed with connection with TITC occur in the months of April and May, with the exception of the case that occurs in June.

*Table 2 – Number of occurrences of cold fronts in Northeast Brazil in the period 2008 to 2017. Gray-case squares with connection between EF and ZCIT.*

| Time course  | D      | J | F | M      | THE | M | J      | J | THE | s      | O | N   | Total |
|--------------|--------|---|---|--------|-----|---|--------|---|-----|--------|---|-----|-------|
| 2008         | 1      |   |   |        |     |   | 1      |   |     | 1      | 1 |     | 4     |
| 2009         |        |   |   |        |     |   |        |   | 1   |        |   |     | 1     |
| 2010         |        |   |   |        | 1   |   | 1      |   | 1   |        |   |     | 3     |
| 2011         |        |   |   |        |     |   | 1      |   |     | 1      | 1 |     | 3     |
| 2012         |        |   |   |        |     |   |        |   |     | 1      |   |     | 1     |
| 2013         |        |   |   |        |     |   |        |   | 1   |        | 1 |     | two   |
| 2014         |        |   |   |        |     | 1 |        |   |     | two    | 1 | 1   | 5     |
| 2015         |        |   |   |        | 1   | 1 |        |   |     |        |   |     | two   |
| 2016         |        | 1 |   |        |     |   |        |   |     |        |   |     | 1     |
| 2017         |        |   |   |        | 1   | 1 |        | 1 |     | 1      |   | two | 6     |
| total/month  | 1      | 1 | 0 | 0      | two | 4 | 3      | 1 | 3   | 6      | 4 | 3   | 27    |
| Linked cases | 0      | 0 | 0 | 0      | 1   | 3 | 1      | 0 | 0   | 0      | 0 | 0   | 5     |
| Seasons      | Summer |   |   | Autumn |     |   | Winter |   |     | Spring |   |     |       |

*Source: Author (2018).*

Two cases of cold front that reached the NEB region were selected for the detailed study, the criterion for choosing the two cases was based on the best seen cases in the fields of relative vorticity and equivalent potential temperature advection. Among the two cases chosen for the detailed study, a cold front case with connection to ZCIT occurred on 10/04/2010 and the other without this connection occurred on 15/05/2015. Several synoptic fields were analyzed such as: Pressure at sea level (hPa), current lines at various levels (1000, 500 and 200 hPa). The work only presents the fields of relative vorticity, equivalent potential temperature advection, accumulated precipitation and satellite images in the infrared channel.

### 3.2. Cold front with connection with ZCIT

#### 3.2.1. Cold front in the satellite image and in the field of relative vorticity.

Through the analysis of the satellite image between 08, 10 and 11/04/2017 (Figure 2), the evolution of the cloudiness band of the cold front and its displacement to the north of the region in the NEB until its junction with the CITZ nebulosity band. The relative vorticity field showed the center of the most intense system (-12S-1) located at 30°S, along the trough associated with the cold front, the maximum vorticity observed during binding is -6S-1 (Figure 2e).

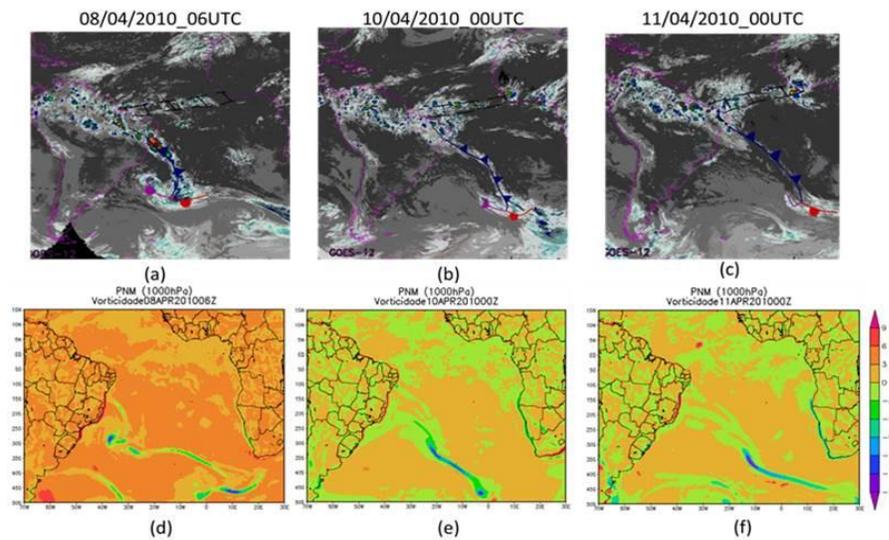


Figure 2 – Satellite images in the infrared channel (a, b, c) and relative vorticity ( $S-1$ ) (d, e, f) of the days 08, 10 and 11/04/2010.

Source: Author (2018).

### 3.2.2. Cold front in the equivalent potential temperature and precipitation fields.

In Figure 3 it is possible to observe the advection fields of equivalent potential temperature and the accumulated precipitation (mm/24h). In the potential equivalent temperature advection field at low levels (1000hPa), one can observe cold advection with a value of (-8 k/6h) at the rear of the cold front and hot advection (6 k/6h) at the forefront (figure 3 b), on this day the binding of the front end cloudiness band with the ZCIT was observed.

The precipitation accumulated in 24 hours on the 8th and 10/04/2010 is above 350 mm in the NEB region (Figure 3d, 3e). On 08/04/2010 there is precipitation along the cold front (Figure 3 d), and on the day when the connection is observed (10/04/2010), precipitation is concentrated in greater quantity on the east coast of the NEB (Figure 3-e).

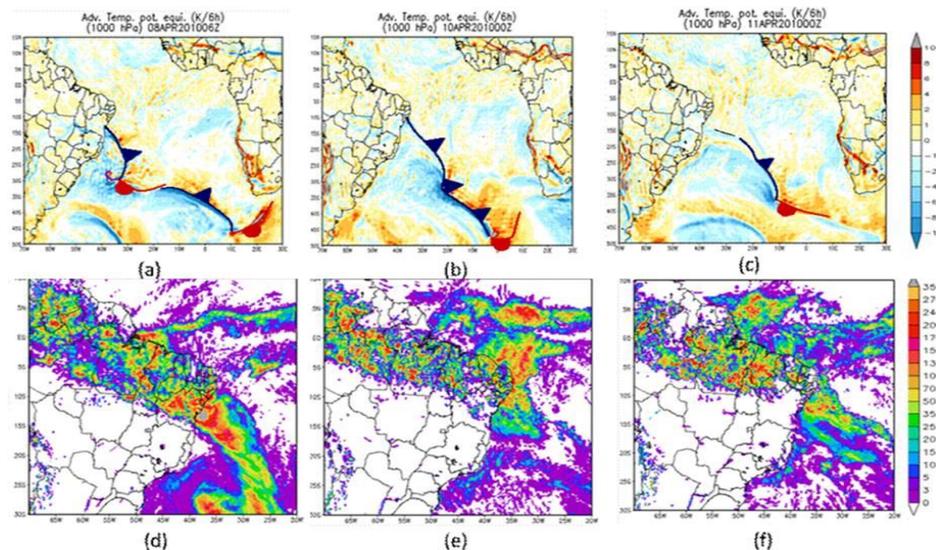


Figure 3 – Equivalent potential temperature advection field (k/6h) at low levels (1000hPa) (a, b, c) and 24h accumulated precipitation for the days 08, 10 and 11/04/2010 (c, d, f).

Source: Author (2018).

In the field of streamlines at high levels (200 hPa), in the NEB region, it showed anticyclonic circulation, and the subtropical jet stream positioned more to the south of South America (17.5°S), without influence on the NEB.

#### 4. Cold front without connection with ZCIT

This item will describe in detail an event without EF connection with ZCIT.

The fields in Figure 4 show the cold front case of 05/15/2015. Through the satellite image it is possible to observe the band of cloudiness associated with the cold front in the south of the northeast (Figure 4 a), during its evolution the cold front reached the state of Sergipe. The ZCIT cloudiness band was positioned further north (5°N) during the performance of the cold front in NEB.

During the evolution of the system, its intensity varied between -3 to -6 S-1 (Figure 4 d, e, f). With the blocking of the subtropical high and the weakening of the trough on the east coast of the NEB (observed in the pressure field), the cold front began its dissipation process on 05/17.

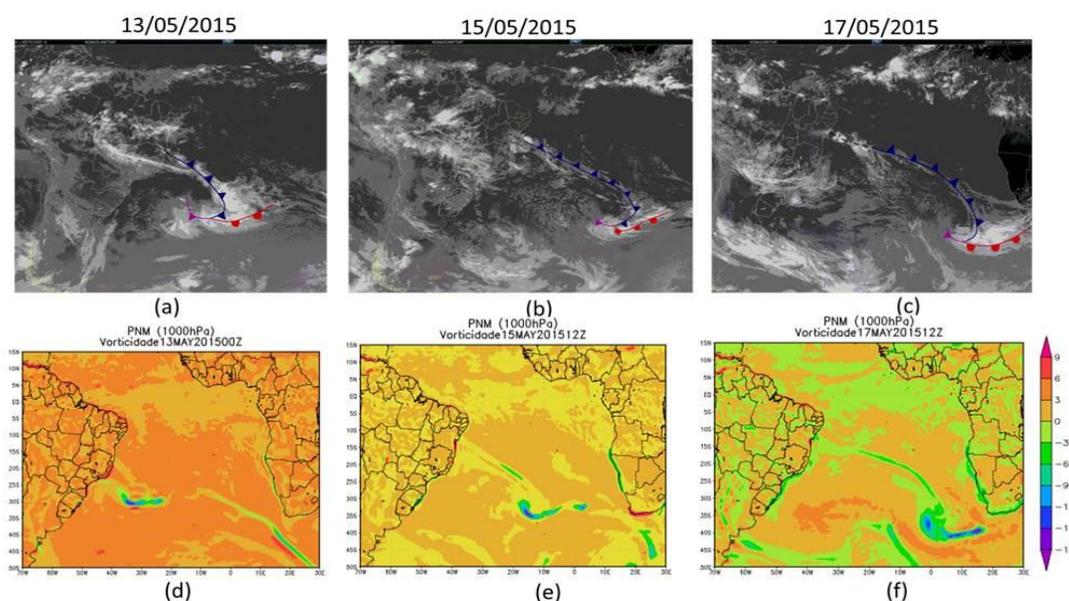


Figure 4 – Satellite images in the infrared channel (a, b, c) and relative vorticity (S-1) on days 13, 15 and 17/05/2010 (d, e, f).

Source: author (2018).

Figure 5 shows the equivalent potential temperature advection field and accumulated precipitation, note the presence of cold advection at the rear of the cold front (-8K/6h) and hot advection at the forefront (6K/6h) (Figure 5a). During the evolution of the system, it is possible to observe its displacement to the NEB region. On 05/15 at 12Z (Figure 5b) it is possible to observe the cold advection in the southern region of Sergipe with a cold advection of -10K/6h, the maximum cold advection recorded along the trajectory of the cold front, and at the forefront of the system Front showed hot advection (4K/6h). The advection field showed that the cold front did not reach the state of Alagoas, the cold advection was limited only to the southern region of Sergipe. In the ZCIT region, hot advection did not have a significant variation, presenting an approximate value at 4K/6k (Figure 5).

Precipitation accumulated in 24 h was observed along the cold front, with the maximum accumulated above 200 mm in the Sergipe region (Figure 5 f).

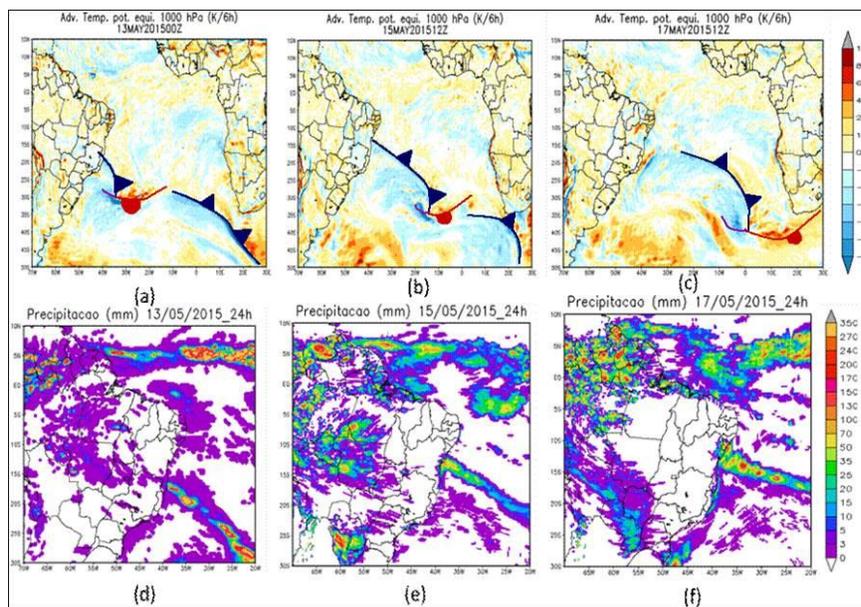


Figure 5 – Potential equivalent temperature advection (K/6h) of the ERA-Interim reanalysis of 00Z of 05/13 (a), 12Z of 05/15 (b), 12Z of 05/17 (c), and accumulated precipitation of days 05/13 (d), 05/15 (e) and 05/17 (f), of the year 2015. Source: Author (2018).

#### 4.1 Circulation at high levels of typical cases with EF-ITZC linkage and without it.

This high-level circulation pattern (200 hPa) observed in Figure 6 was seen in all typical cases with EF binding with ZCIT (a) and without this binding (b), highlighting CJST position and NEB circulation. In cases with connection in the NEB region without influence of CJST, anticyclonic circulation in (200 hPa) and records of heavy rainfall in all cases, as shown in the example of the case with connection (Figure 3 d, e, f) and in the cases without this connection, with influence of the output of CJST in NEB, cyclonic circulation in (200 hPa) and no record of heavy rains in NEB, example in Figure 5 e.

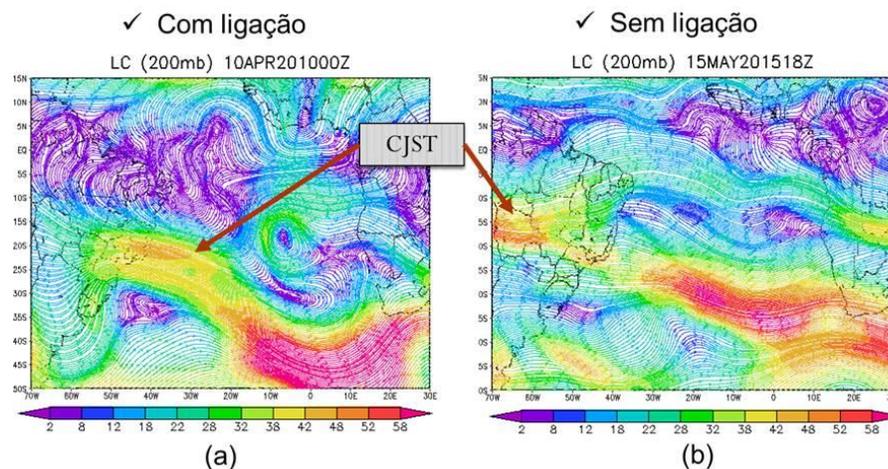


Figure 6 – Current line fields at and high levels (200 hPa) (a) with connection (b) without connection at 00Z 18Z on 10/04/2010 and 15/05/2015 respectively, purple arrows-CJST position. Source: Author (2018).

#### 4.2. Comparisons of events with connection of the frontal zone with ZCIT and without this connection.

Four cases with the front end bonding with ZCIT showed similar chain structure. In the fifth case with this connection, VCAN was present. The differences in the structure of the chains are described below. Note the small variation in the position of the ZCIT (0 to 3°S) off the coast of Brazil in the 5 cases (Figure 7 a, b, c, d). At high levels in 4 cases it was anticyclonic circulation and CJS influence between 16° to 25°S. The centers of the cyclones associated with the frontal systems that had a connection with the ZCIT were observed in the 20°W longitude, varying only in the latitude, between 35°S and 20°S. The case of cold front connection with ITTCZ in the presence of VCAN (Figure 7 e) followed the pattern of the other 4 cases in relation to the positioning of the ITTCT.

The unconnected cases showed the presence of a subtropical jet stream in the NEB influencing the weather in the region (only one case is shown in Figure 7 f with bifurcation in the jet stream). This was not seen in NEB in all cases with front lesson with ZCIT.

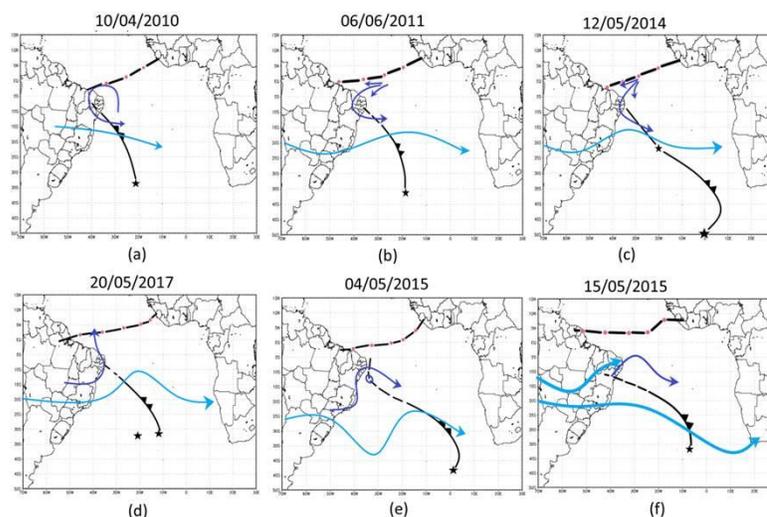


Figure 7 – Conceptual model of the structure of the Atmosphere at various levels of cases with FF end connection with ZCIT and one case without such connection. Lines: dark blue – circulation at high levels; light blue – jet stream at high levels; dotted discontinuous black – position of the intertropical convergence zone; star center of the cyclone.

Source: Author (2018).

#### 4.3. Characteristics of events with connection of the frontal zone with ZCIT

The characteristics of 5 cases with connection of the frontal zone with ZCIT are presented in table 3. This table shows maximum values of the relative vorticity ( $S^{-1}$ ) in the center of the cyclone, in the trough of the cyclone associated with the FF, advection of ( $\theta_e$ ) ( $K/6h$ ) in the region of interest (where it is observed connection of the cloudiness band at the front end with ZCIT), position of the cyclone at the moment of connection of the two systems and wind circulation at high levels (200 hPa).

Satellite images showed front-end nebulosity binding to the ZCIT in all 5 cases. 4 (four) cases showed the same values of relative vorticity in the trough ( $-5 S^{-1}$ ) during binding (II., III., IV. and V. respectively), with the exception of case I, which showed greater intensity with vorticity relative equal to  $-10 S^{-1}$ . The vorticity in the center of the cyclones associated with the troughs of the cold fronts, its intensity varied between  $-25$  to  $-15 S^{-1}$ . Theta advection in the binding region of the two systems ranged from  $-6$  to  $-5 K/6h$ .

##### 4.3.1. Conditions of joining or not of the frontal zone with ZCIT.

##### 4.3.2. Conditions for joining the frontal zone with ZCIT

Tropospheric circulation patterns in the NEB region were established to help predict frontal systems and, subsequently, weather in the region (Figure 6). One of the main conditions for the penetration of the fronts in the NEB region was the position of the subtropical jet stream.

The main characteristics of the circulation conducive to the entry of fronts into the NEB and connection with the ZCIT are as follows:

- 1 – Absence of the influence of the subtropical jet stream (CJS) on the NEB, which allows the entrance of frontal systems to the north of the NEB;
- 2 – Predominance of high-level anticyclonic circulation in the NEB region, which shifts the subtropical jet stream to the south of South America;
- 3 - Well-known connection of classic type VCAN (GAN & KOUSKY, 1986) with frontal areas helps in the penetration of the fronts in the NEB.

#### 4.3.3. Conditions for a frontal system not reaching north of NEB

- 1 – Influence of the subtropical jet stream (CJS) on the NEB makes it impossible to enter frontal systems to the north of the NEB;
- 2 - Cyclonic circulation at high levels (200 hPa) blocks the penetration of fronts in the region.

##### 4.3.3.1. Analysis of the phenomena associated with the events of the connection of the frontal zone with ZCIT.

Meteorological stations recorded heavy rain and wet mist in all events (Table 2). Fog, stratus clouds and thunderstorms were not observed in any season.

Table 3 – Rain data and meteorological phenomena in events with connection of the front end with ZCIT. +RA - heavy rain; BR - Wet Mist.

| Dates      | Rain | wet mist | Stratus | Fog | thunderstorms |
|------------|------|----------|---------|-----|---------------|
| 10/04/2010 | +RA  | BR       | -       | -   | -             |
| 06/06/2011 | +RA  | BR       | -       | -   | -             |
| 12/05/2014 | +RA  | BR       | -       | -   | -             |
| 05/04/2015 | +RA  | BR       | -       | -   | -             |
| 05/20/2017 | +RA  | BR       | -       | -   | -             |

Source: Author (2018).

The case with extreme rain occurred in May 2017, recording an accumulation of precipitation above 350 mm between 25th and 05/28/2017, causing floods and landslides. This precipitation associated with the frontal end and the ZCIT in the NEB caused several damages in the region, according to the Civil Defense of Alagoas (<https://g1.globo.com/al/alagoas/noticia/chuvas-fortes-causam-deslizamentos-de-barreiras-e-deixam-mortos-e-ferados-em-maceio.ghtml>).

## 5. Final considerations

Frontal zones over the NEB were observed between 2008 and 2017, with greater frequency between the months of September, October and November. During the study period, 27 cases of cold fronts were observed. Among these cases, 5 (five) cases of cold front had connection with the ZCIT. Cases with connection were observed in the months of April, May and June.

A detailed study of cold front events was made, from formation, displacement until reaching the northern region of the NEB. Satellite images showed connection of front end cloudiness with the ZCIT in 5 (five) cases. The synoptic analysis performed showed in 4 (four) cases the same values of relative vorticity in the trough (-5 S-1) and one case showed relative

vorticity in the trough -10 S-1. The vorticity in the center of the cyclones associated with the troughs of the cold fronts linked to the ZCIT had its intensity between -25 S-1 to -15 S-1. The equivalent potential temperature advection ( $\theta_e$ ) at the rear of the front end in the NEB region showed values between -6 to -5 K/6h, and at the forefront it presented values between 2 to 6 K/6h, in all cases with connection front end with ZCIT.

The structure of the troposphere in cases of cold front with connection with ZCIT was determined as follows:

- In 5 cases there was a small variation in the position of the ZCIT around 0 to 3°S in the NEB region, observed by the confluence of the northeast and southeast trades at low levels (1000 hPa);
- The centers of cyclones associated with the frontal systems with connection with ZCIT were located at longitude 20°W, varying only in latitude, between 35°S and 20°S;
- Wind confluence was observed at the edge of the cold fronts in the NEB region, contributing to convection in the region of the cold front connection with ZCIT;
- At high levels (200 hPa) 4 cases had anticyclonic circulation and in one case it was cyclonic circulation. The subtropical jet stream in the 5 (five) cases was located further south (16° to 25° S) of South America, not influencing the NEB region.

Tropospheric patterns were elaborated in situations of union or not of the frontal zone with ZCIT. These patterns were established to aid in the prediction of frontal and sequential weather systems in the NEB region. These standards were based on the differences presented between the cold front cases with union with ZCIT and without union, the standards are:

#### **I. Front end union with ZCIT**

- 1 – position of the subtropical jet stream approximately in southwestern Brazil, with no influence on the NEB region;
- 2 – Anticyclonic circulation at high levels (200 hPa) in the NEB, contributing to the displacement of the subtropical jet stream in southwestern Brazil, allowing the displacement of cold fronts to the north of the NEB.

#### **II. No front end joint with ZCIT**

- 1 – Position of the subtropical jet stream in NEB, with influence on the region;
- 2 – Cyclonic circulation at high levels (200 hPa) in the NEB region, contributing to the displacement of the jet stream to the NEB region, blocking the entrance of frontal systems to the north of the NEB.

Adverse phenomena were identified in the events with cold front connection with the ZCIT. In all events, wet mist and heavy rain were observed in the NEB region. Thunderstorms, stratus were not observed at the NEB meteorological stations. Highlighting the event of connection of the frontal zone with ZCIT, registered rainfall above 350 mm between the 25th and the 28th of May, 2017. During the permanence of the detached end of the cold front in the NEB region, floods were recorded in several points of Alagoas and landslides, causing destruction of material goods and causing 4 deaths.

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