Chapter

Impacts of Tropical Cyclones in the Northern Atlantic on Adverse Phenomena Formation in Northeastern Brazil

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Abstract

Tropical cyclone (TC) impacts on adverse phenomena in the tropical region of Northeastern Brazil (NEB) have been analyzed. TC influence on fog and rain formation was not described in the previous papers. The main goal of the chapter is to evaluate the existence of such influence and thus to improve the weather forecasting in this area. TC information from the NHC of the NOAA was used. METAR and SYNOP data were used for the adverse phenomena study. Analysis of the synoptic systems was based on different maps at the pattern levels and on satellite images. These maps were elaborated using reanalysis data from the ECMWF. Thermodynamic analysis was also used. Middle tropospheric cyclonic vortexes (MTCV) in the tropical region of the Southern Atlantic were described recently. Five from 10 MTCVs were associated with tropical cyclones and disturbances in the Northern Atlantic. Circulation patterns between TC and synoptic systems at the NEB are described. These circulations create sinking over the BNE and, as a result, form fog, mist and weak rain in the BNE during TC days. Mechanisms of TC influence on weather formation in the BNE are presented. This information is important for improving weather forecasting methods.

Keywords: tropical cyclones, Northeast Brazil, adverse phenomena

1. Introduction

Fog and mist events are rare and show significant variation of frequency in the tropical region of the Brazilian Northeast (BNE) [1, 2]. Radiosonde data in the central and south regions of the BNE, i.e., Recife, Pernambuco state (8°S, 35°W), and Salvador, Bahia state (13°S, 39°W), registered fog (haze) on average in 13 (13) and 37 (41) days per year, respectively [3]. On the other hand, in the first study of fog formation in Maceio, Alagoas State (9°S, 39°W) [4], only two fog events (moderate and weak) during 1996 (both in winter) were found. Fog does not exist in the semiarid region [3]. In the northern region of the BNE, i.e., Belem, Para State (1°S, 48°W), and Quixeramobim, Ceara State (5°S, 39°W), fog (haze) was registered in

24 (1) and 4 (28) events/year, respectively. More frequently, fog was observed in Barra do Corda, Maranhao State (5°S, 45°W), in 48 days/year, but haze was very rare, only 4 days/year. Also, fog duration was very short, 1–2 h on average in the coastal region of the BNE [5].

Moreover, the physical mechanism of fog formation on the northern coast was atypical (typical radiation or advection fog does not occur typically) [6]. Summarizing the results of this chapter, it was possible to make the following conclusion regarding the processes of fog formation in the tropical region of the BNE. A weak confluence at the low-level trough (wave disturbances in trade winds—WDTW) contributes to weak pressure anomaly and creates the conditions for moisture convergence as well. A change in wind direction and air current from the river region contributes additional humidity for fog formation. Also, precipitation occurred before the fog events, contributing to humidification of the air through evaporation of the humid surface and raindrops. A warmer sea surface contributes to more evaporation and, as a consequence, increases the amount of water vapor in the surrounding air at the low levels near the coast. Positive latent heat flux shows a humidity increase and, therefore, moisture accumulation in the coastal region. Negative sensible heat flux results in air cooling, possible water vapor condensation, and, finally, fog formation.

All this information about rare fog events with a short duration and atypical physical mechanisms of their formation demonstrates the numerous problems for fog/haze forecasting.

An intertropical convergence zone (ITCZ), a South Atlantic subtropical high (SASH), trade winds, and an upper tropospheric cyclonic vortex are typical synoptic scale systems associated with different weather conditions in the BNE [7].

For the first time, the influence of wave disturbances in trade winds (WDTW) on rain formation in the BNE was shown in Molion and Bernardo [8]. The relationship between different types of troughs and adverse meteorological phenomena (fog and thunderstorms) in Alagoas State was studied by Rodrigues et al. [9]. It was noted that 87% of the troughs were associated with wave disturbances in trade winds (WDTW) on the northwestern periphery of the subtropical South Atlantic High. Rare stratus cloud events with a duration of 4 days each on the northeast coast of Brazil also were formed in WDTW [10]. Fog formation is usually associated with WDTW in Maceio (Alagoas State) [1, 5, 6, 11].

The influence of the Brazilian Northeast Jet Stream (BNEJS) on weather in the BNE was described recently [12–14]. Particularly, the results of this study show that the period from April to October (a rainy period and the transition to a dry season in the coastal region) was characterized by a rather high number of fast BNEJSs, with high wind speed in the core, a predominant northwesterly direction, and the location of BNEJS between the upper tropospheric trough (UTT) and the SASH.

Upper tropospheric cyclonic vortices (UTCVs) are important synoptic scale systems in this region; the greatest UTCV frequency occurs during the austral summer period, with the maximum frequency in January [15–18]. Intensive cloud development with precipitation was observed on the UTCV periphery and cloudlessness in their center as a result of a downward motion in its cold center and upward motion on the periphery. Rao and Bonatti [18] conjectured that barotropic instability of the regional mean basic winds at the upper levels could be one cause for UTCV formation. It was suggested that these air streams are associated with the subtropical jet stream and contribute to UTCV development. A strong positive shear zone was formed within the South Atlantic trough before the formation of the UTCV [19]. The same paper showed that the barotropic process dominates over the baroclinic one. They showed that barotropic energy conservation is the energy source for the growth of wave motion and wave amplitude and also that barotropic instability of the shear zone can excite the UTCV.

Middle tropospheric cyclonic vortices (MTCVs) located between 700 and 400 hPa in the BNE were described recently [20, 21]. About 232 MTCVs were observed each year over the BNE and adjacent ocean region. MTCVs were predominantly short and lasted less than 12 h. The vortices persisting longer than 30 h were detected more frequently in the summer and rarely in autumn.

Frontal zones are observed regularly in the southern region of the Brazilian Northeast in the Southern Hemisphere (SH) [22, 23]. The influence of a western edge of a frontal cloud band on the weather conditions was found in the central region of the Brazilian Northeast SH and was described by Fedorova et al. [24]. The western edge of a frontal cloud band rarely passes across Alagoas State in the BNE. Only two to five frontal zones per year which directly affected the weather conditions were observed in 2004–2006. Nonetheless, Reeder and Smith [25] quoted different papers (including [26, 27]) where a cold front crossing the equator and penetrating the Northern Hemisphere (NH) tropics was documented. These fronts can initiate severe convection in the subtropic SH; however, they generally tend to suppress convection in the ITCZ.

A SASH was observed in the South Atlantic during the whole year and was located at the low levels in the eastern part of the South Atlantic, on average between 20°W and 30°S [7, 28]. It migrated from 15°W, 27°S in August, to 5°W, 33°S in February [29]. A SASH in summer is frequently split and is normally weaker [7].

Some studies show the influence of synoptic scale systems of the Northern Hemisphere on BNE weather. The influence of tropical cyclone Dany-15 on intensive fog formation in the NEB was descried by Fedorova and Levit [1]. But the information about tropical cyclone (TC) impact on BNE weather over many years has not yet been presented. Thus, the main aim of this chapter is to analyze the impact of all tropical cyclones formed from 2013 to 2015 between 20°N and the equator and which passed through 35–50°W, on fog, mist, and weak rain formation in the BNE.

2. Data and methodology

2.1 Selection and classification of the tropical cyclones

All tropical cyclones (TC) formed from 2013 to 2015 between 20°N and the equator whose centers passed through 35–50°W have been studied, using data from the National Hurricane Center's Tropical Cyclone Reports https://www.nhc.noaa.gov/data/tcr/.

TC has been classified according to their sustained wind speed [30] as follows:

Tropical disturbance (*TD*). In this stage, winds are less than 17 m/s with open circulation (no closed isobars).

Tropical depression (*TDep*). Winds are less than 17 m/s, but there is a closed circulation (closed isobars).

Tropical storm (*TS*). Winds are greater than or equal to 17 m/s but less than 33 m/s with a definite closed circulation. The storm is usually assigned a name.

Hurricane (*H*). Winds greater than or equal to 33 m/s.

Major hurricane (*MH*). Typhoon with 1 min of sustained winds of 65 m/s or greater (*MH* was not observed during the study period).

2.2 Analysis of meteorological phenomenon in the BNE

Fog, mist, and weak rain events in the BNE were analyzed by SYNOP and METAR data. The BNE area and location of all meteorological stations are presented in **Figure 1**.

2.3 Synoptic and thermodynamic analysis

Synoptic analysis was elaborated in the equatorial and tropical regions of both hemispheres between 30°N and 30°S and by latitude between 10°W and 60°W. This region includes the BNE, part of the South Atlantic and the TCs moving over the North Atlantic region.

The tropospheric structure for all TC events has been studied using data from the European Center for Medium-Range Weather Forecasts (ECMWF), with a resolution of 0.25°× 0.25°, 00, 12, 18 UTC (http://apps.ecmwf.int/datasets/data/interim-full-daily/levtype=pl). Streamlines have been elaborated at the low (1000 hPa), middle (500 hPa), and high levels (300 and 200 hPa). Divergence maps were constructed only at the high levels (300 and 200 hPa). Both horizontal maps and vertical sections were used for vertical movement identification. These vertical sections passed through the TC center and the BNE region at the same longitude. Satellite infrared images from the GOES-13 and METEOSAT-10 (http://bancodedados.cptec.inpe.br) were used for synoptic system identification.

Thermodynamic analysis was elaborated for the days with fog, mist, and weak rain in the BNE. Vertical profiles were constructed using the same data from the ECMWF quoted above.

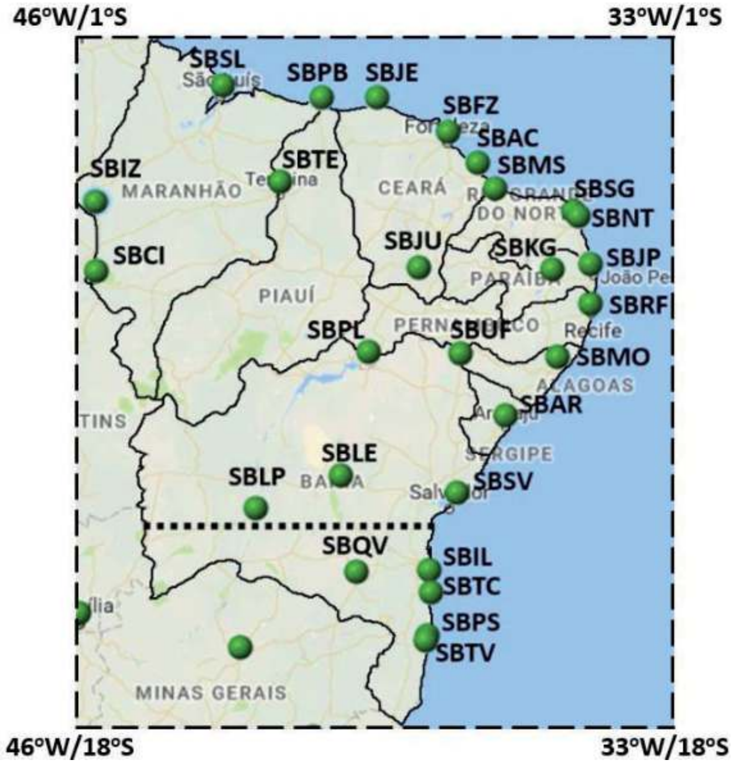

Figure 1.
The location of the BNE, States, and all meteorological stations (green points) with names.

3. Results

3.1 Information about tropical cyclones

Information about tropical cyclones (TC) formed during 2013–2015 between 20°N and the equator and passing through 35–50°W is presented in **Table 1**. Ten tropical cyclones were registered during this time period, and their influences have been analyzed. Five TCs were observed in 2015, three of them in 2013 and only two in 2014.

3.2 Information about fog, mist, and rain formation by METAR and SYNOP data

Information about fog, mist, and weak rain events in the BNE by METAR data when TCs passed through 35–50°W is presented in **Figure 2** and **Table 2**. Two examples of maps with this information are presented in **Figure 2**. Fog, mist. and weak rain events were observed more frequently in the coastal region, e.g., **Figure 2**. Only one fog event was registered far from the coastal region, occurring in the Maranhao State (SBIZ station) (**Figure 2a**). Fog, mist, and weak rain events were observed more frequently in the southern region of the BNE, in the Bahia State. Six events were registered in the southern region of the Bahia (SBQV), not far from the coastal region (300 km approximately). Also, fog was detected in the coastal stations of this region (SBIL and SBPS). Only one event was recorded in the northern coastal region in the Pernambuco State (SBRF). An influence of seven TCs on fog rain formation in the BNE was confirmed (**Table 2**). During three TCs (Edouard, Fred, and Grace), METAR data did not record any fog events; at the same time, weak rain and mist were detected. A *Tropical disturbance and Tropical storm* were the predominant TC stages during its influence on the weather in the BNE.

Name	Data			TC intensity	
	Formation	Dissipation	BNE longitude	Maximal	BNE longitude
2013					
Chantal	06 July	10 July	7–10 July	*TS*	*TS*
Dorian	22 July	03 August	24–27 July	*TS*	*TS*
Erin	15 August	20 August	16–20 August	*TS*	*TS-D*
2014					
Bertha	29 July	06 August	29–31 July	*H*	*TD*
Edouard	10 September	23 September	10–14 September	*H*	*TD-H*
2015					
Danny	17 August	24 August	17–22 August	*H*	*TD-H*
Erika	24 August	28 August	24–25 August	*TS*	*TS*
Fred	30 August	06 September	02–05 September	*H*	*TS-TDep*
Grace	05 September	09 September	06–09 September	*TS*	*TS-D*
Ida	15 September	28 September	17–28 September	*TS*	*TD-D*

TD, tropical disturbance; TDep, tropical depression; TS, tropical storm; H, hurricane; D, dissipation. Source: National Hurricane Center, 2017.

Table 1.
Information about time period and intensity of tropical cyclones (TC).

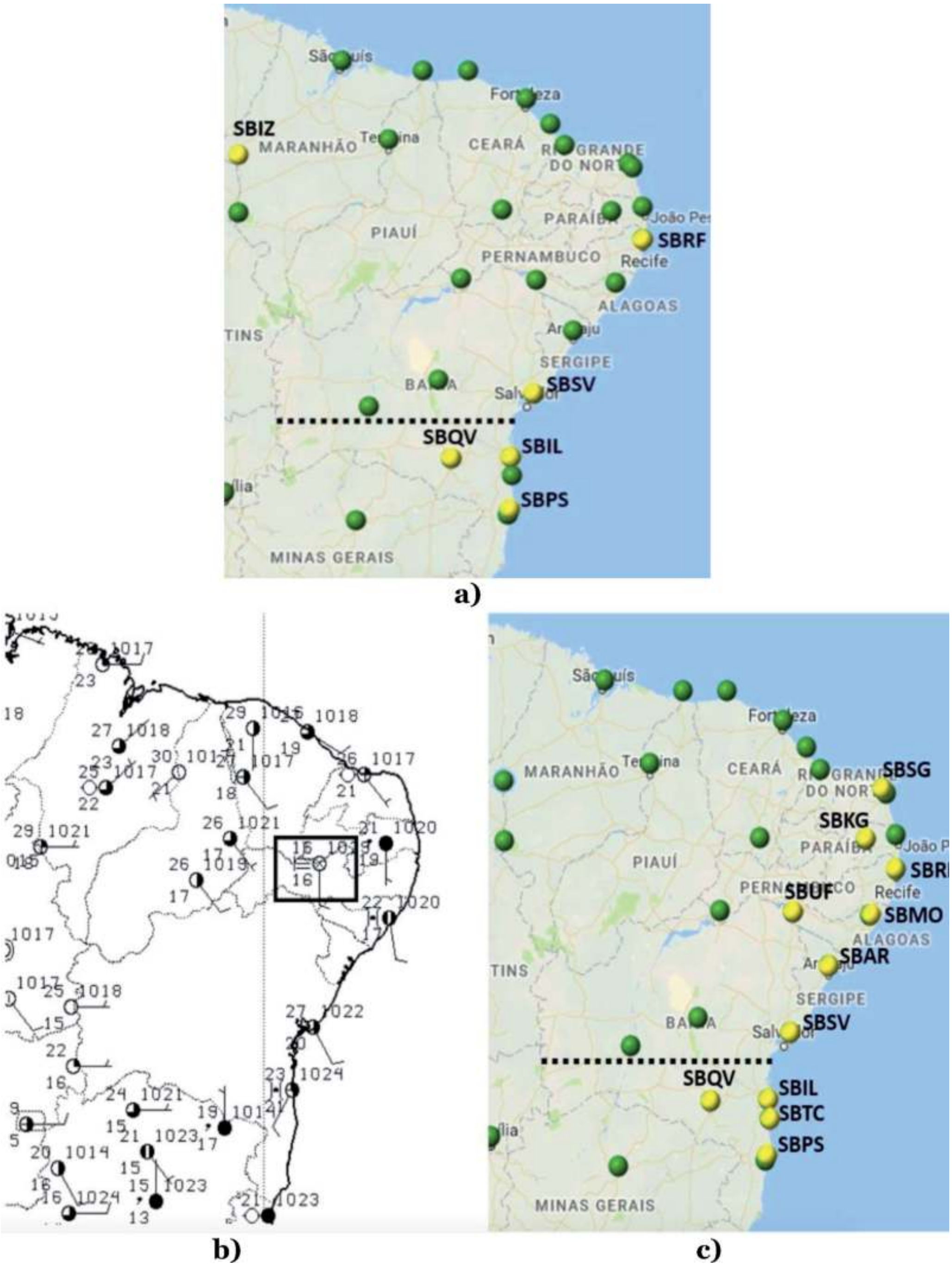

Figure 2.
(a) Location of the meteorological stations detected fog (yellow points) in the BNE by METAR during all TC events. (b) and (c) Location of the meteorological stations detected mist events (yellow points) 29 July 2014 12 UTC in the BNE by METAR (c) and SYNOP (b). Green points mark all meteorological stations.

3.3 Synoptic systems associated with fog events

3.3.1 1000 hPa

A synoptic situation at 1000 hPa was very similar during all fog, mist, and weak rain events (**Table 3**). Trade winds presented cyclonic curvature (*weak trough*) over the ocean close to the coastal area and anticyclonic curvature (*weak ridge*) over the

TC name, *stage*	**Data**	**State**	**Station**	**Hours (local)**
2013				
Chantal *TS*	08 July	Bahia South	SBQV	08, 09
Dorian *TS*	**22** July	Bahia South	SBQV	10, 11
	25 July	Paraiba	SBKG	06, 09, 10
	25 July	Maranhao	SBIZ	08
	26 July	Paraiba	SBKG	03–08
		Paraiba		*06*
Erin *TS*	**15** August	Bahia North	SBSV	08–10
	18 August	Pernambuco	SBRF	15
		Pernambuco		*12*
2014				
Bertha *TD*	*29 July*	*Pernambuco*		*12*
	31 July	Bahia South	SBQV	10, 11
	01 August	Bahia South	SBQV	09
Edouard	—	—	—	
2015				
Danny *TD*	*17 August*	*Pernambuco*		*12*
	20 August	Bahia South	SBQV	09, 10
	21 August	Paraiba	SBKG	04, 05
	21 August	Bahia South	SBQV	10, 11
Erika *TS*	24 August	Bahia South	SBIL	09, 10
Fred	—	—	—	—
Grace	—	—	—	—
Ida *TD*	18 September	Bahia South	SBPS	09

Bold data show the information when a TC passes before or after the BNE longitudes. TD, tropical disturbance; TS, tropical storm. Source: DECEA, 2017.

Table 2.
Information (TC name, state, station, and hour) about fog events in the BNE by METAR data and SYNOP data (inclined) during the time period with TC passing through 35–50°W.

northern region of the BNE (**Figure 3**). This weak trough was located close to the frontal extremity over the south of the Bahia State in five events. It is important to note that a frontal extremity does not have a direct influence in the fog region but has action on trough formation.

3.3.2 500 hPa

Anticyclonic circulation over the BNE was the predominant process at the middle levels in days with fog, mist, and weak rain events (**Figure 4**, **Table 3**). Also, a convergence zone was observed in the north and middle regions of the BNE in all events. This convergence zone was formed between the currents from a tropical cyclone or tropical depression in the Northern Hemisphere and this anticyclonic circulation in the Southern Hemisphere. The current from the NH was formed as a result of the divergence at the middle levels of the tropical cyclone or tropical depression. For example, **Figure 3** shows airflow from the tropical depression on the west coast of Africa (6°N) converging with the air current of the high (with the center at 6°S, 54°W).

TC name, ***stage***	**1000 hPa**	**500 hPa**	**200/300 hPa**
2013			
Chantal *TS*	*TO/RC* (7), *TO/RC/FZ* (8,9)	A (7–9)	*TCO* (6, 7) A (8) *TCO* (9) SJSHS 10–15°
Dorian *TS*	*TO/RC/FZ* (22–26)	A (22–25), MTCVo (23–25)	A (22–23) *TCO* (24, 25) A (26, 27) SJSHS 20°
Erin	*TO/RC/FZ* (16–17)	MTCVc, A (16–18)	A (16) *TCO* (17) A (18) SJSHS 20°
2014			
Bertha *TDis*	*TO/RC/FZ* (29–31–1)	A (29–31–1)	*TCO* (29–31–1), SJSHS 10–15°
Edouard	*TO/RC* (10–13)	A (10), MTCVc (10, 11)	*TCO* (10–11) A (12–13) SJSHS 10–15°
2015			
Danny *TDis*	*TO/RC* (17–19), *TO/RC/FZ* (20–21)	A, MTCVc (17–18), A (19–22)	*TCO* (17–20) SJSHS 10–15° (17–20)
Erika	*TO/RC/FZ* (24–26)	A (24–26)	*TCO* (24–26) SJSHS 10–15° (24–26)
Fred	*TO/RC* (1) *TO/RC/FZ* (2–3)	A (1–4)	*TCO* (1–2) A (3–4) SJSHS 10–15°
Grace	*TW(6–9)*	A (7–9)	*TCO* (7) A (8–9) SJSHS 10–15°
Ida	*TO/RC* (16–18)	A (16–17) MTCVo A (16–17)	A (17–19)

A, anticyclonic circulation; TO (trough over the ocean); RC (ridge over the continent); TW, trade winds nearly straight (no pronounced curvature); FZ (frontal zone), TCO (trough at the middle and high levels over the continent and ocean); SJSHS (subtropical jet stream of the Southern Hemisphere)—location of the northern boundary (°W); MTCVo and MTCVc—middle tropospheric cyclonic vortices over the oceanic and continental regions, respectively. Information inside brackets represents number of days.

Table 3.
Synoptic systems in the BNE at the low (1000 hPa), middle (500 hPa), and high (300 and 200 hPa) levels during tropical cyclones in the northern hemisphere.

Middle tropospheric cyclonic vortices (MTCV) were observed in five studied events (**Table 3**). MTCVs were located over the adjacent ocean region in two of the five events, in the northeastern part and in the coastal region of the continent in one case each. Four MTCVs were typical in terms of the level of its location and duration, were short, and lasted 6–12 h. Only one MTCV lasted 36 h, and its center was located in the south of the BNE, and its circulation affected only southern part of the BNE. The MTCVs created the waves on the air current from the NH but did not change the principal influence of this northern current. Meanwhile one MTCV on 17 Ag 2013, 12UTC, was formed between west flow of the SH and

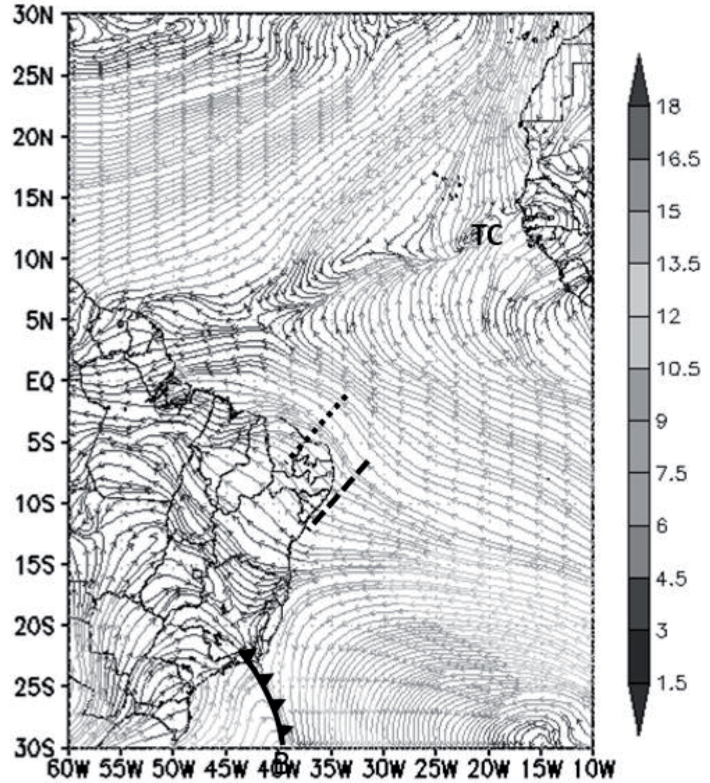

Figure 3.
Streamlines at 1000 hPa on 22 July 2013, 18 UTC. Trough, dashed line; ridge, dotted line; and TC, tropical cyclone.

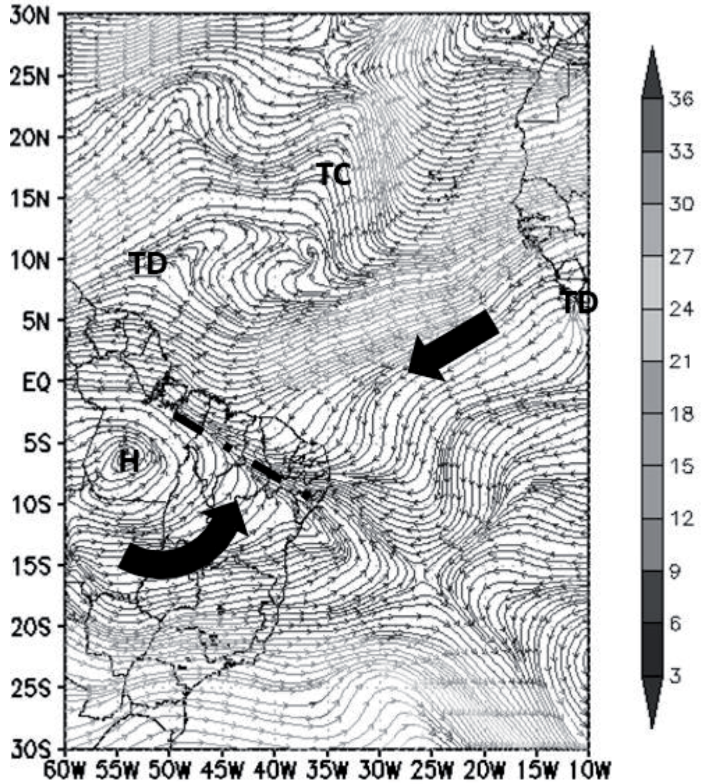

Figure 4.
Streamlines at 500 hPa, 17 August 2013, 00UTC. H, anticyclonic circulation; TD, tropical disturbance; TC, tropical cyclone; and -•-•-, convergence zone.

northeast current from the tropical disturbance of the NH near Africa and lasted 6 h. Other four MTCVs were formed in the flow of the southern hemisphere without the TC influence.

3.3.3 200/300 hPa

The principal influence of the NH flow was observed at the high levels (**Figure 5**, **Table 3**). Divergent flow was observed at the high levels in the TC. The height of this divergent flow depended on the TC intensity and was registered at 300 and 200 hPa. This divergent flow at the high levels passed through the equator to the BNE region. This flow from the TC was connected with anticyclonic circulation over the equatorial and south Atlantic. Thus, a single current was formed in the Northern Hemisphere, from the north or northeast.

Also, the anticyclonic circulation was predominant over the central and south region of the BNE. The location of this high was dependent upon the subtropical jet stream of the Southern Hemisphere (SJSHS). The northern boundary of this jet stream reached 15 or 30°W in the study events and was not observed over the BNE region. Curvature of the SJSHS was cyclonic (*trough*, *upper tropospheric trough*) over the continental region and anticyclonic (*ridge*) over the ocean region.

These two currents from the Northern Hemisphere and anticyclonic circulation of the Southern Hemisphere created the convergence of air current which, in turn, produced air sinking.

Two examples of this flow at the high levels can be seen in **Figures 5** and **6**. The difference between these examples is in the location of the Highs over the Atlantic Ocean. Meanwhile, the location of the convergence zone over the BNE was very similar.

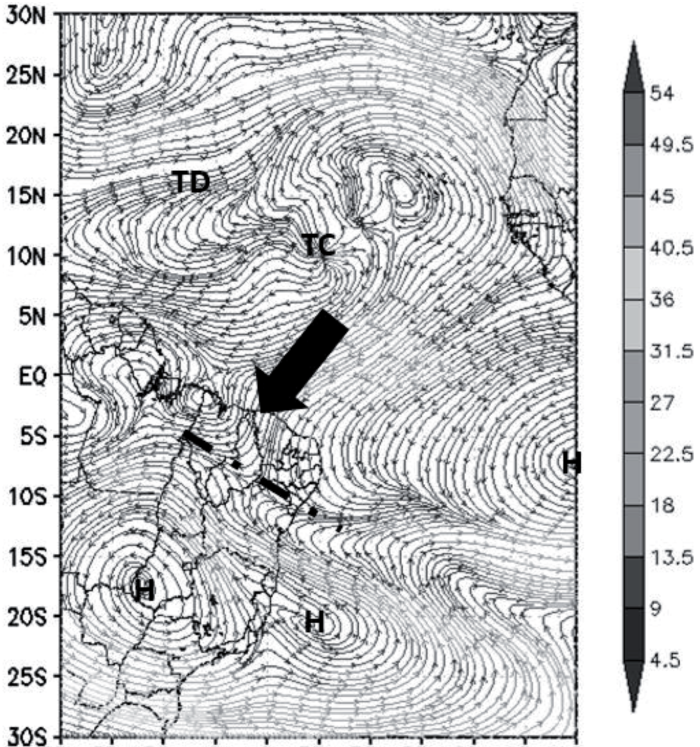

Figure 5.
Streamlines at 300 hPa 18 September 2015, 12UTC. H, anticyclonic circulation; TD, tropical disturbance; and TC, tropical cyclone. -•-•-, convergence zone.

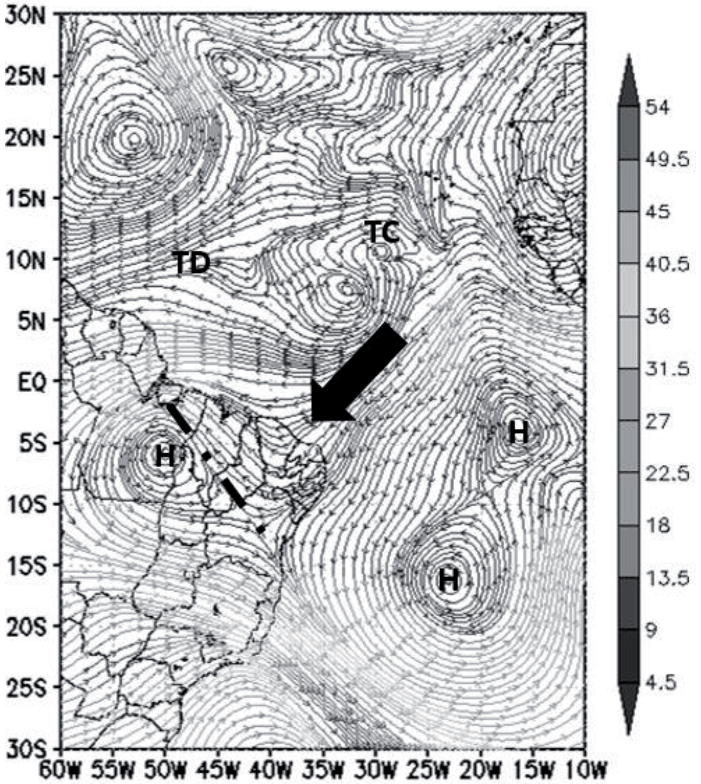

Figure 6.
Streamlines at 300 hPa 16 August 2013, 00UTC. H, *anticyclonic circulation;* TD, *tropical disturbance;* TC, *tropical cyclone; and -• -• -, convergence zone.*

A slightly different situation was observed during the TC Dorian on 25 July 2013 (**Figure 7**). This difference was associated with jet stream formation from the Northern to Southern Hemisphere, denominated as the Brazilian Northeast Jet Stream—BNEJS [20]. The data from this paper shows that, generally, BNEJS from the north was observed very rarely. On this day, the BNEJS was formed between two highs: in the north (near Maranhao State, high 1) and northeast of Brazil (high 2). The high 1 location was more to the north than the typical high position described before. At the same time, the high 2 location was close to the continental region, with its center on the northeastern cape of the South American continent. These highs squeezed the flow from the TC, and so the BNEJS was created. Also, the northern boundary of the SJSHS reached 15°W on this day. Therefore, the convergence zone between the currents from the south and north was detected in the south BNE region.

A scheme of the synoptic systems, observed more frequently at all levels simultaneously during the TC and fog events, is presented in **Figure 8**. This figure shows the circulation pattern, which contributes to fog, mist, and weak rain formation in the BNE. As a result of this circulation, a convergence zone at the middle and high levels and anticyclonic circulation at the middle levels were formed.

3.4 Mechanism of fog, mist, and weak rain formation

The circulation described in Section 3.3 creates sinking over the BNE. Vertical movements were analyzed in all events, and an example of this vertical motion is presented in **Figure 9**. Lifting in TC Bertha can be seen in **Figure 9a** and **d**. The vertical movement reaches 0.3 m/s. Very intense diffluent current was observed at

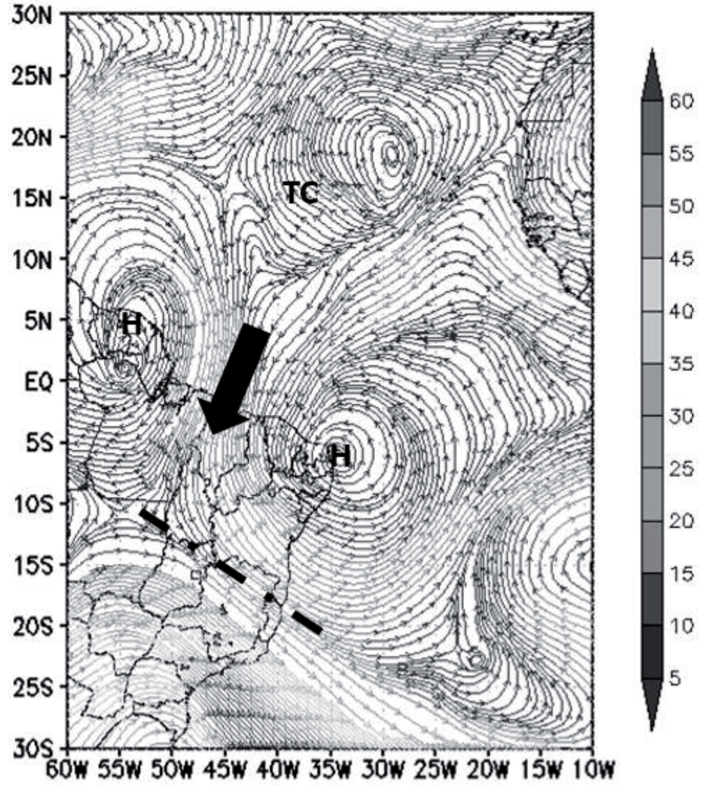

Figure 7.

Streamlines at 200 hPa, 25 July 2013, 06UTC. H, anticyclonic circulation; TC, tropical cyclone; and -•-•-, convergence zone. The black arrows show the BNEJS.

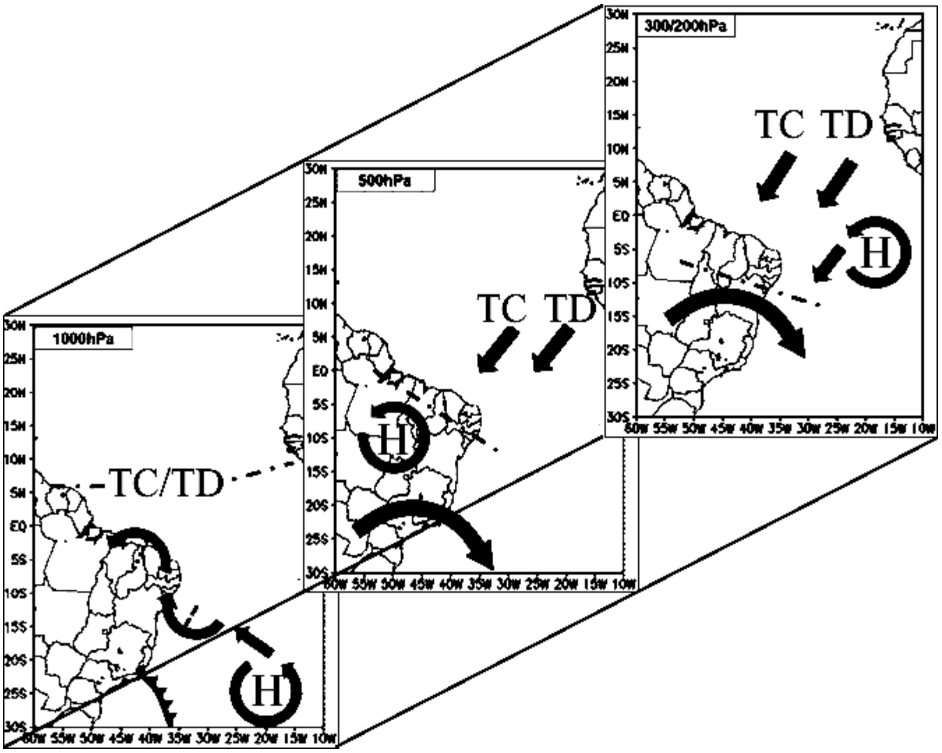

Figure 8.

Synoptic systems, observed more frequently at all levels simultaneously. TD, tropical disturbance; and TC, tropical cyclone.

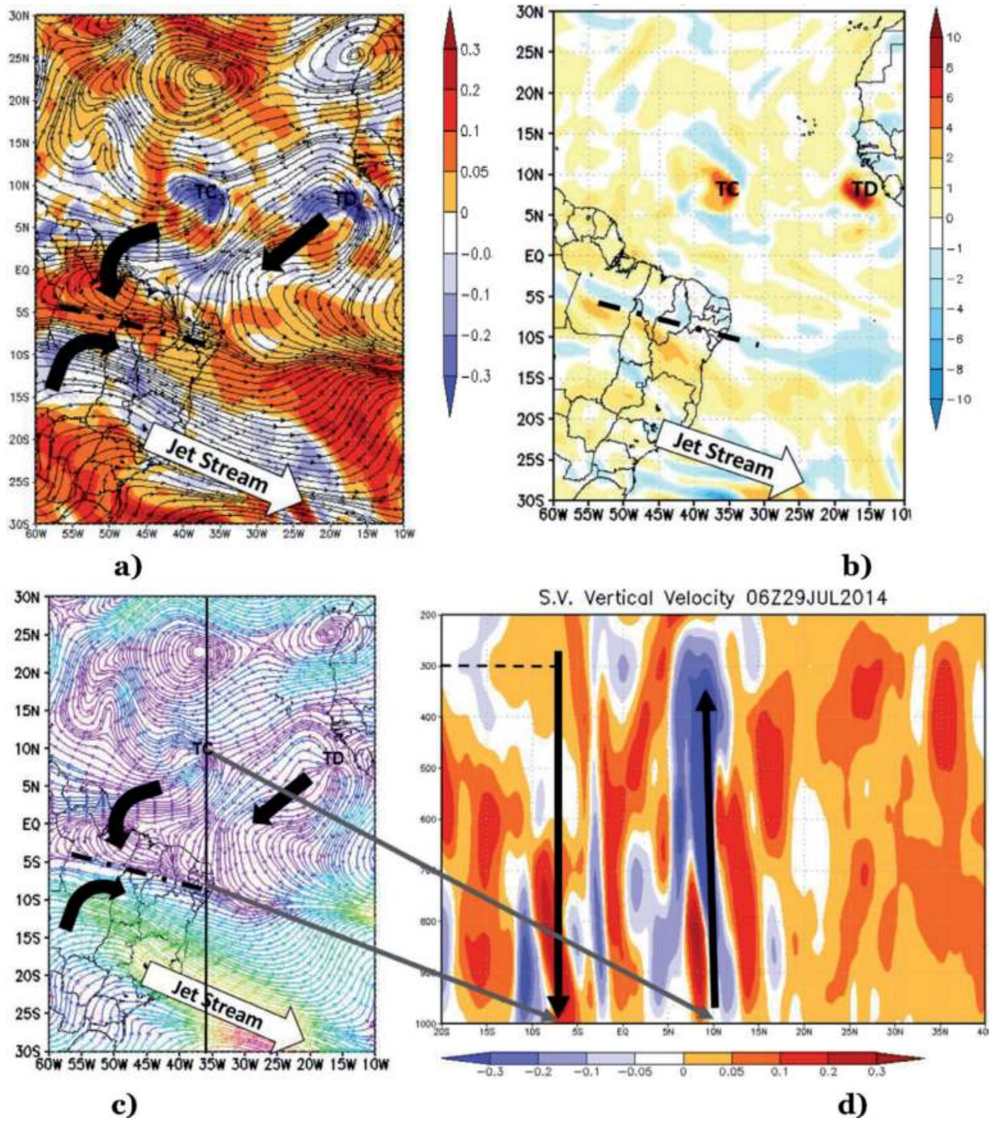

Figure 9.
Circulation between TC, TD is, and fog formation region on 29 June 2014, 06 UTC, in different maps: Vertical velocity (a, Pa s^{-1}) and divergence (b, s^{-1}), streamlines and wind velocity (c, m s^{-1}) all at 300 hPa and (d) vertical section of vertical velocity (Pa s^{-1}) along 37.1°W (longitude of TC Bertha).

300 hPa in TC Bertha (**Figure 9b**). Airflow at the high levels from TC Bertha to the BNE is presented in **Figure 9a** and **c**.

These circulations create sinking over the BNE and, as a result, humidity accumulation at the low levels and fog, mist, and weak rain formation. These phenomena were detected as the principal adverse phenomena in the BNE during all TC days.

4. Conclusion

The impact of all studied (10) TCs on the weather conditions in the BNE was analyzed during July to September from 2013 to 2015. These TCs had a *tropical storm* stage, when passing between 35 and 50°W and up to 20°N in the Northern Hemisphere. Only one, TC Bertha, had the stage of *tropical disturbance (TDis)* during its passage in this area.

The fog, mist, and weak rain in the BNE were the adverse phenomena associated more frequently with these TCs. Days with mist were also accompanied by weak rain. These phenomena were observed in all TC events and predominantly near the coastal region of the BNE.

The synoptic situation at 1000 hPa shows a wave disturbance near the BNE coastal area with a weak trough over the ocean close to the coastal area and a weak ridge over the northern region of the BNE. This situation was detected in all study events. Frontal extremity over the south of the Bahia State had an influence on trough intensification.

The convergence zone at the middle levels in the northern or middle region of the BNE was formed in all fog events between the currents from a TC in the Northern Hemisphere and anticyclonic circulation in the Southern Hemisphere. This anticyclonic circulation was predominant over the greater part of the BNE. Middle tropospheric cyclonic vortices were observed during half of the events but did not change the principal influence of the airflow from the TCs. One MTCV was formed between west flow of the Southern Hemisphere and northeast current from the tropical disturbance of the Northern Hemisphere.

The airflow at the high levels from the Northern Hemisphere is formed by the coupling (joining) of two currents: (1) from a TC and (2) from the high over the equatorial and south Atlantic. The confluence of these airflows with the current from the trough created by the subtropical jet stream of the Southern Hemisphere was the principal mechanism of the sinking in the BNE.

This sinking over the BNE formed the accumulation of humidity at the low levels and, as a result, fog, mist, and weak rain formation. Therefore, fog, mist, and weak rain were the principal adverse phenomena in the BNE during TC days.

This information can be used for short-term forecasting of adverse phenomena, such as fog and mist with weak rain in the BNE.

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