Title: "Study of two Upper Cold Lows and their relationship with locally intense rain."

Title: "Locally intense rain in Cuba under the influence of Upper Cold Lows. Study of cases. "

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Abstract

The main objective of the research is to determine the synoptic and mesoscale conditions which under the influence of two Upper Cold Lows (BFSs) favor the occurrence of locally intense rain in Cuba. From the outputs of the Rapid Refresh (RAP) model, the characteristics of two BFSs with four cases of locally intense rain associated with them are analyzed. The variables that are studied are: relative humidity, temperature, geopotential height, vertical speed, wind force, divergence and vorticity. Mesoscale conditions are analyzed using the Weather Research and Forecast System (WRF) model. Vertical cuts, numerical soundings and analysis of radar observations and satellite images are carried out.

Keywords: upper cold low; locally heavy rain

INTRODUCTION

Intense rains are a dangerous meteorological phenomenon, as they tend to cause notable floods of bodies of water, associated with significant floods of fluvial origin, which affects natural ecosystems and human intervention (Planos *et al.*, 2007 Guantánamo. Laguardia (2011) performs a climatology of the BFSs that influence the Cuban territory, as well as an analysis of their characteristics and temporal and seasonal behavior. According to Benhamrouche and Martín - Vide (2012), the BFSs are systems that encourage the occurrence of locally intense rain, which in turn can take place in a season due to local factors, not occurring in the surrounding territories (Planos *et al*., 2004). Therefore, the general objective of the research is to determine the synoptic and mesoscale conditions that under the influence of two Upper Cold Lows (BFSs) favor the occurrence of locally intense rain in Cuba.

MATERIALS AND METHODS

Sample selection

The study area covered the entire Cuban territory. The selection of the case studies was based on the analysis of the General Weather (EGT) reports, prepared by the Weather Forecast Center of the Institute of Meteorology of Cuba (INSMET). The first criterion for the search of the case studies, focused on the selection of those days in which there was locally intense rain under a BFS pattern that was located on or near Cuba. However, in order to determine the influence of the systems, mechanisms and processes of the different meteorological scales and their interaction, it was proposed as a second requirement that the case studies should include at least three days under the influence of the weather. Same synoptic pattern and, in at least one, the event in question has been generated.

Two study cases were selected, each with three consecutive days, which were: July 2, 3 and 4, 2016 and August 16, 17 and 18, 2016 (Table 1), reporting locally intense rain in the first two days of each case. In three of them there were accumulations of more than 100 mm in 24 hours collected by the Network of Rain Gauges of the National Institute of Hydraulic Resources (INRH) and in one 50 mm in 12 hours recorded by the Batabanó meteorological station.

Table 1. Spatial and temporal location of the cases of locally intense rain with their respective accumulations.

Day	Month	Year	Location	Province	Latitude	Length	Precipitation value (mm)	Time (hours)
2	7	2016	La Sierpe	Sancti Spíritus	21.81 °	-79.23 °	101	24
3	7	2016	Colón	Matanzas	22.76 °	-80.97 °	177	24
16	8	2016	El Salvador	Guantánamo	20.33 °	-75.36 °	106	24
17	8	2016	Batabanó	Mayabeque	22.73 °	-82.28 °	61	12

Computing tools

During the three consecutive days in which each BFS influenced Cuba and where there were cases of locally intense rain, a synoptic analysis with a higher spatial and temporal resolution was needed to identify the changes that occurred in the BFS. Fue to this fact, the outputs of the High Resolution Rapid Refresh (RAP) Numerical Weather Prediction Model (MNPT) and the Grid Analysis and Display System (GrADS) computational tool were used.

Because a storm cloud can be less than the 13 km spatial resolution of the RAP model, it was necessary to work with the atmospheric Weather Research and Forescat System (WRF) model with a resolution of 3 km and up to 1 km. This way it was possible to make a more exhaustive study of the storms that produced the locally intense rains.

Programming language and software used

For the work with the data of the RAP and WRF model, the implementation of the mathematical algorithm that was developed in order to determine the different parameters and variables, as well as for the graphical outputs of the results, the Python programming language was used on its 2.7 and 3.6 versions. Meanwhile, for the interpolation and graphical output of the precipitation, the softwares System Automated Geoscientific Analyzes (SAGA) and Quantum Geografic Information System (QGIS), and MS - Access for the organization of the data were used.

Methods

The variables used, both for the mesoscale analysis and for the synoptic analysis, were extracted directly from the WRF and RAP models, respectively. Through these, other variables were obtained from the solution of mathematical equations, with the aim of having a greater amount of data for a better characterization of the BFSs and their influence on locally intense rain.

With the RAP model, the variables were analyzed from the surface to the level of 100 hPa, emphasizing the 700-200 hPa layer, as this is where the BFSs have the best representation (Carlson, 1967). More emphasis was placed on temperature, geopotential, wind force, as well as its vertical speed, since according to Alfonso *et al*. (1990) for the study of BFSs these fields can be used successfully. In addition, the maximum, minimum and average values in the domain of the BFSs were calculated, considering the last closed isohypsa. The WRF model was used for the surface layer - 500 hPa, in order to analyze the storms that produced the locally intense rains.

RESULTS AND DISCUSSION

Synoptic description

The origin of the BFS corresponding to the case study of July 2, 3 and 4, took place within a deep trough that extended from an upper low, associated with a system of extratropical low pressures. The BFS corresponding to the case study of August 16, 17 and 18, originated within the TUTT on the western Atlantic.

According to the criterion of Frank (1970), the BFSs that are reflected from the upper troposphere up to 500 hPa are classified as wet and those that remain above that level, as dry. Taking this criterion into account, it was possible to classify the BFS of July 2, 3 and 4 as humid, having representation up to 500 hPa. On the other hand, the BFS that affected during August 16, 17 and 18, is classified as dry, because it remained above 500 hPa. The wet BFS lasted for a period of 8 days and the dry one for 5 days; both moved to the west and at the end of their evolution, to the northwest, which caused them to affect the entire Cuban territory.

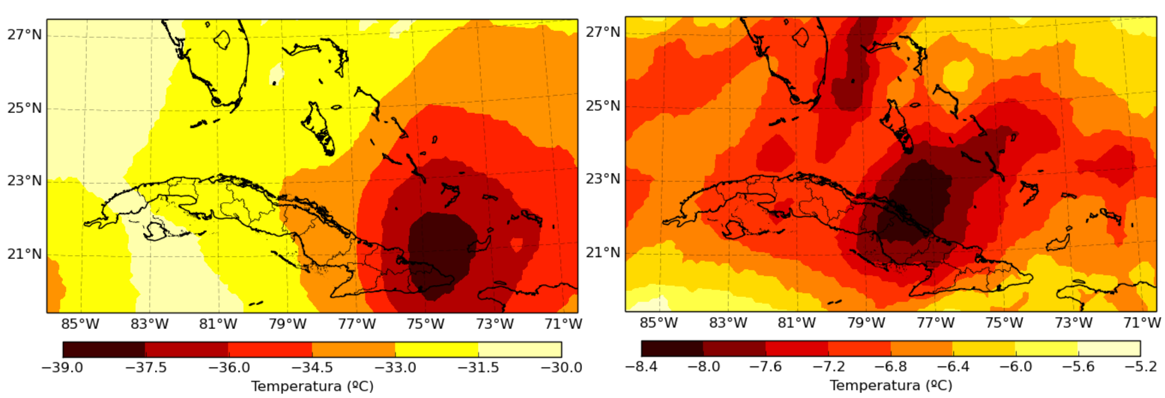
Analysis of the BFSs from the RAP model

From the data of the RAP model, an analysis of the BFSs was carried out in order to characterize them in greater depth and see their possible influence on the generation of locally intense rain.

Temperature

Because BFSs are better defined at 200 and 300 hPa, these two levels were analyzed in greater depth. From now on, the first value will always correspond to the 200 hPa level and the second to the 300 hPa level. The BFS corresponding to July 2, 3 and 4 had an absolute minimum temperature of -58.24°C and -38.50°C.

The average value comprised in the downstream domain was also calculated, taking as a reference the last closed isohypse, which turned out to be -54.10°C and -33.60°C. The BFS corresponding to August 16, 17 and 18 had an absolute minimum temperature of -56.36°C and -38.50°C, the average values in the domain of the system considering the last closed isohypsa were -52.97°C and -33.12°C. In both cases, the variable had its best representation at 300 hPa, although a core of maximum temperature values is observed from 200 hPa to below 500 hPa (Figure 1).



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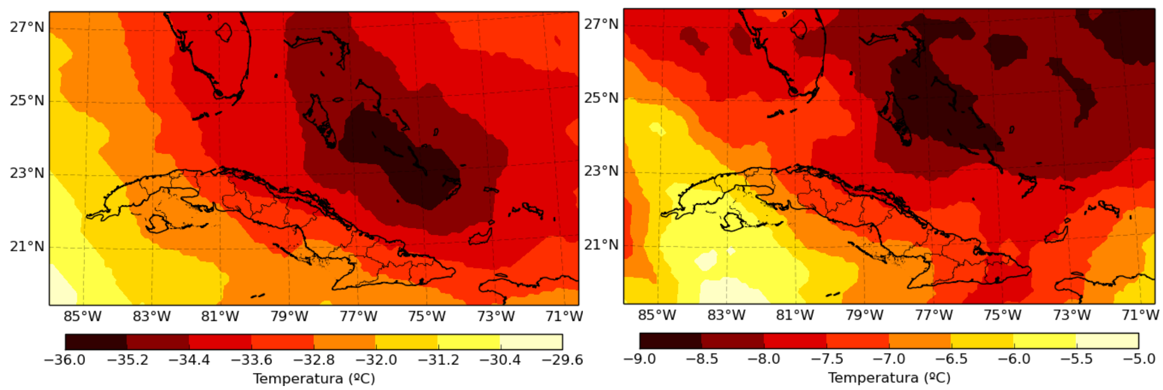
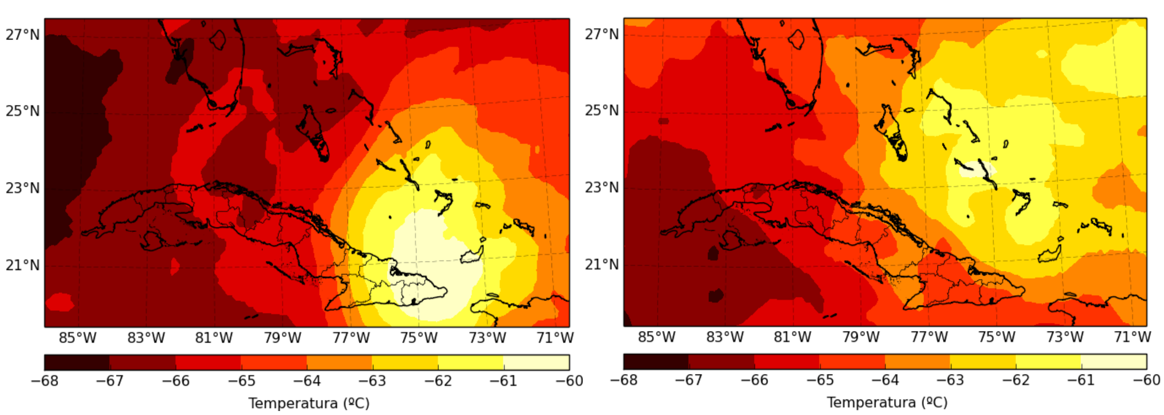


(c) **(d)**

Figure 1. Temperature at the level of 300 and 500 hPa corresponding to (a) and (c) July 2 at 1400 UTC and (b) and (d) August 16 at 1300 UTC.

The cold air mass associated with the BFSs in their respective centers generated a strong vertical temperature gradient greater than 6.7×10^{-3} (°C/m), between the surface and the level of 500 hPa. This, along with mesoscale mechanisms, was able to produce strong convective activity in the afternoon. Consequently, great positive buoyancy was generated in the atmosphere surrounding these systems, favoring the rise of the air mass and creating synoptic conditions conducive to the convective development of cloudiness.

Another feature to highlight is the warm core that was observed in both BFSs above the 200 hPa level, having its best representation at 150 hPa (Figure 2). This coincides with what was found by Laguardia (2011) in his climatological study of 479 BFSs, which suggested the existence of positive anomalies towards the lower stratosphere. Pérez (2019) described the observed warming in the lower stratosphere as a great enigma.

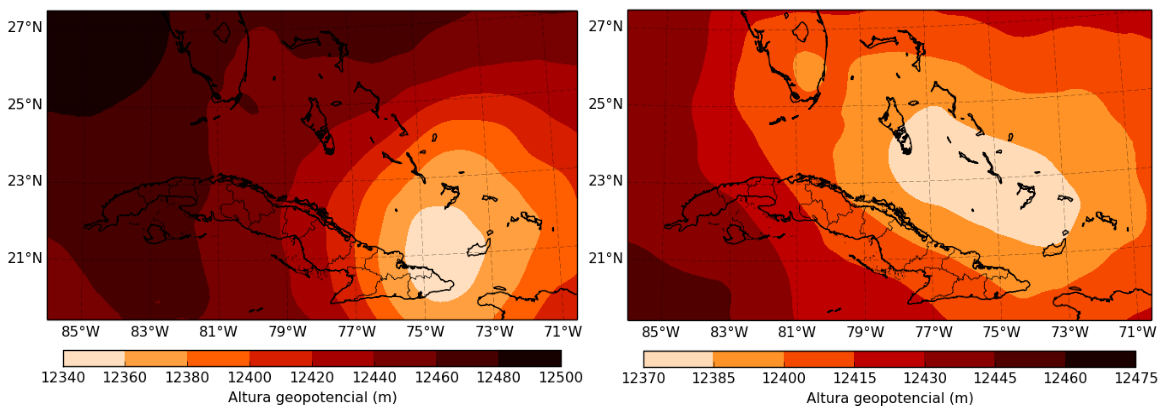


(a) **(b)**

Figure 2. Temperature at the level at the 150 hPa level corresponding to (a) July 2 at 1400 UTC and (b) August 16 at 1300 UTC.

Geopotential height

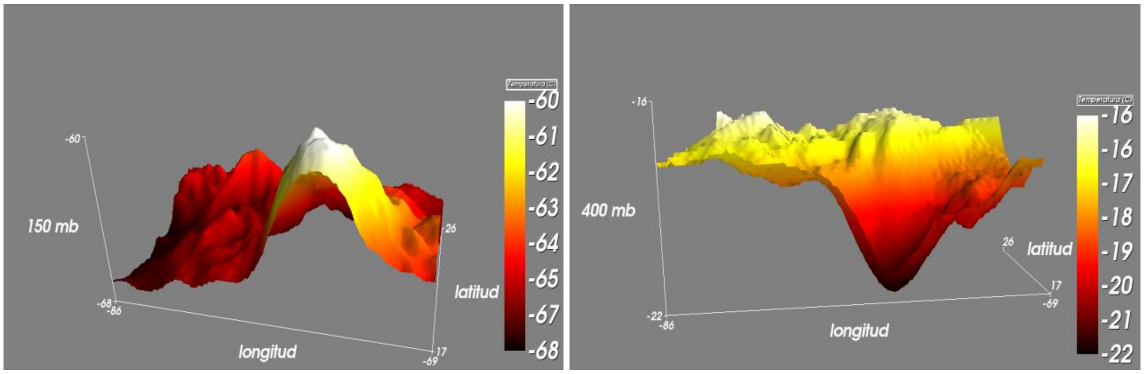
The geopotential height of the BFS for the month of July presented absolute minimum values of 12 341 mgp and 9644 mgp, the area that enclosed the last closed isohypsa had significant values of 12 427 mgp and 9714 mgp. The August BFS presented absolute minimums of 12 365 and 9650 mgp, the significant values in the BFS domain reached 12 418 mgp and 9696 mgp. In the two systems analyzed, this variable had its best representation at 200 hPa (Figure 3), being able to be seen in a general way from 125 hPa to 450 hPa.



(a) **(b)**

Figure 3. Geopotential height at the 200 hPa level corresponding to (a) July 2 at 1400 UTC and (b) August 16 at 1300 UTC.

A three-dimensional analysis of the two BFSs was performed between the 150 hPa levels, at 400 hPa in the case of temperature and from 100 to 400 hPa in the case of geopotential height (Figure 4). This showed the deformation of both of the fields' variables had as they descended in altitude, which represents the fall of the values towards the center of the system, where the extremes meet. The behavior is similar in the two cases, since they decrease proportionally, however, the temperature at the 150 hPa level increases towards the central region.



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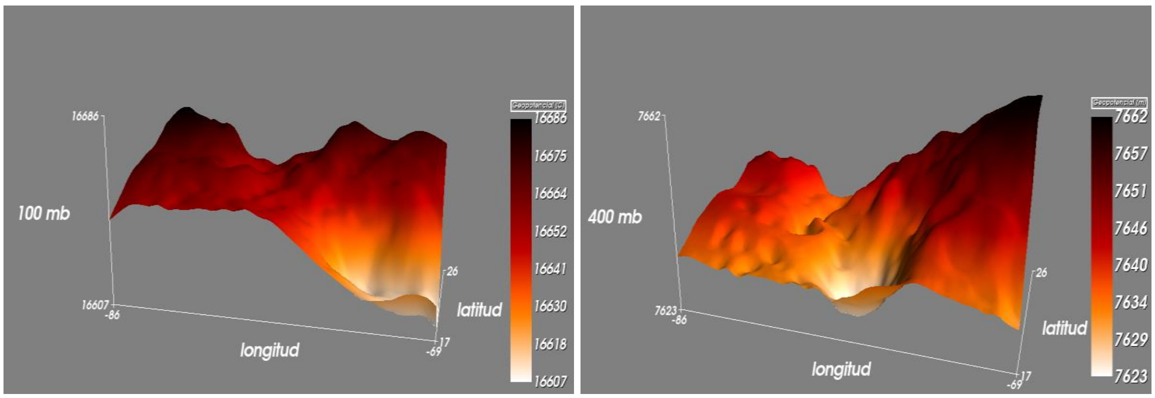
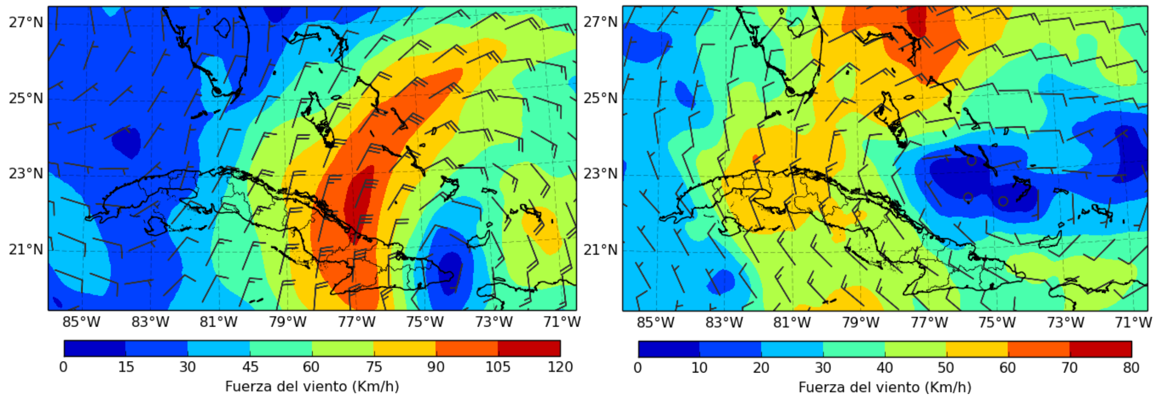


(c) **(d)**

Figure 4. Temperature fields and geopotential height at the levels (a) 150 hPa, (b) 400 hPa, (c) 100 hPa and (d) 400 hPa respectively, for July 2, 2016 at 1400 UTC.

Wind speed

The wind speed analysis reflected that the circulation of both systems was present from 125 hPa to 450 hPa, being better defined at 200 hPa (Figure 5), where the maximum values of wind speed occurred with 121 km/h for the BFS for July and 95 km/h for the August.

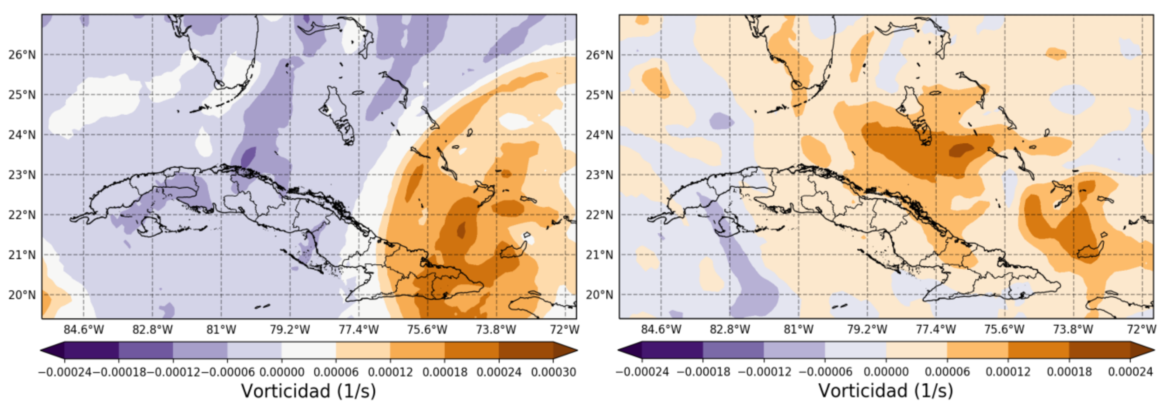


(a) **(b)**

Figure 5. Wind speed and direction at the 200 hPa level corresponding to (a) July 2 at 1400 UTC and (b) August 16 at 1300 UTC.

Relative vorticity

The level of 200 hPa was where the cyclonic vorticity generated by both systems was best represented (Figure 6), because its circulation was better defined on this. The BFS for the month of July had an absolute maximum value of $3.94 \times 10^{-3} s^{-1}$ at the level of 200 hPa, higher than that presented by the BFS for August with 2.5×10^{-3} s^{-1}.



(a) **(b)**

Figure 6. Vorticity at the 200 hPa level corresponding to (a) July 2 at 1400 UTC and (b) August 16 at 1300 UTC.

CAPE and LI

The CAPE and the LI had their most representative values in the area that enclosed the last closed isohypsa of the BFSs, being more significant for the case corresponding to days 2, 3 and 4 of July (Figure 7 (a) and (b)). The CAPE values in this ranged between 4500 and 6200 J/kg and the LI between -10 and -15. In the case corresponding to August 16, 17 and 18, the values were between 3500 and 4800 J/kg and -9 and -13, respectively (Figure 7 (c) and (d)).

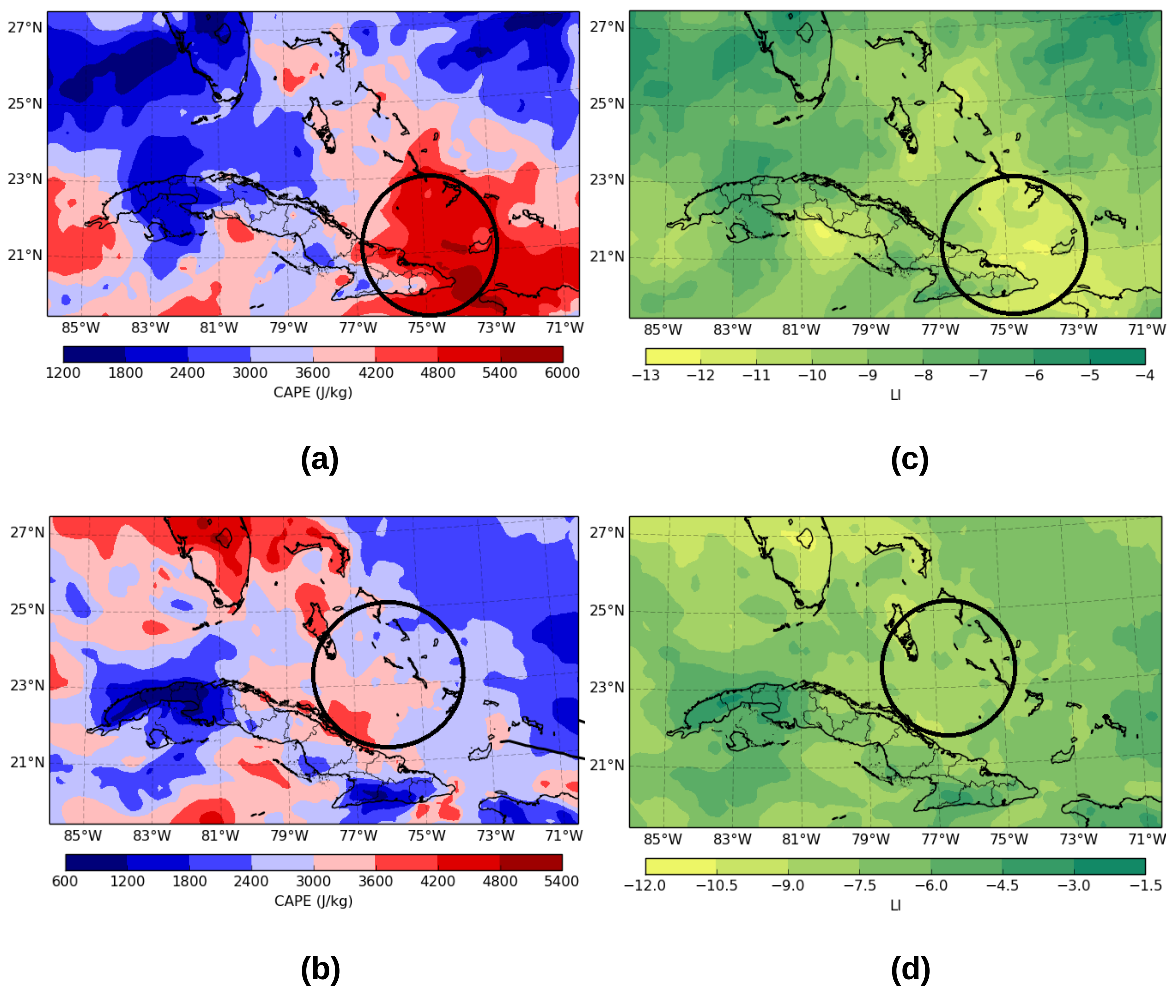
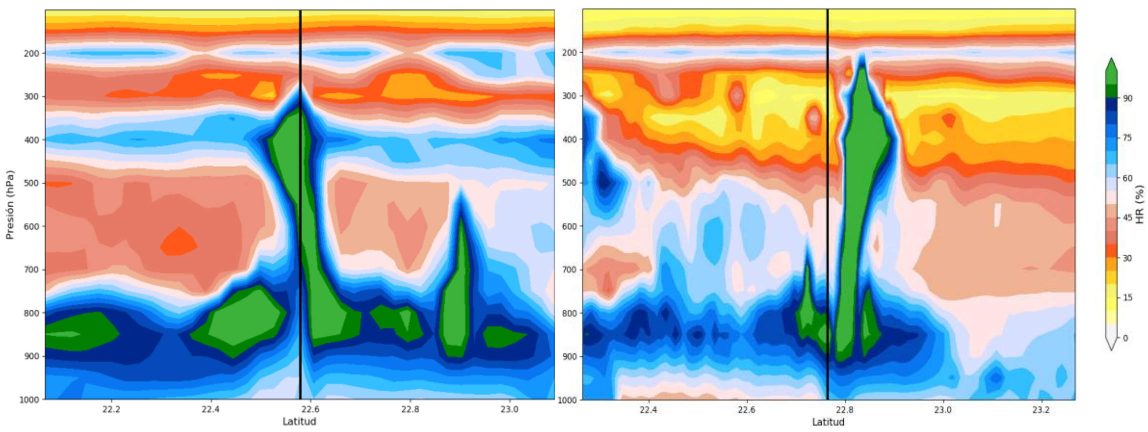


Figure 7. CAPE and LI values at the 200 hPa level corresponding to ((a) and (b)) July 2 at 2200 UTC and ((c) and (d)) August 16 at 1400 UTC.

Mesoscale analysis of variables and indices from the WRF model

In the four cases analyzed, two wet layers were present in the tropospheric column, one of them was located between 1000 and 800 hPa, with values greater than 70% and the other one was between 300 and 200 hPa with a magnitude greater than 60 %. In addition, a dry layer could be seen, which extended from 700 hPa to 300 hPa with values lower than 45%.

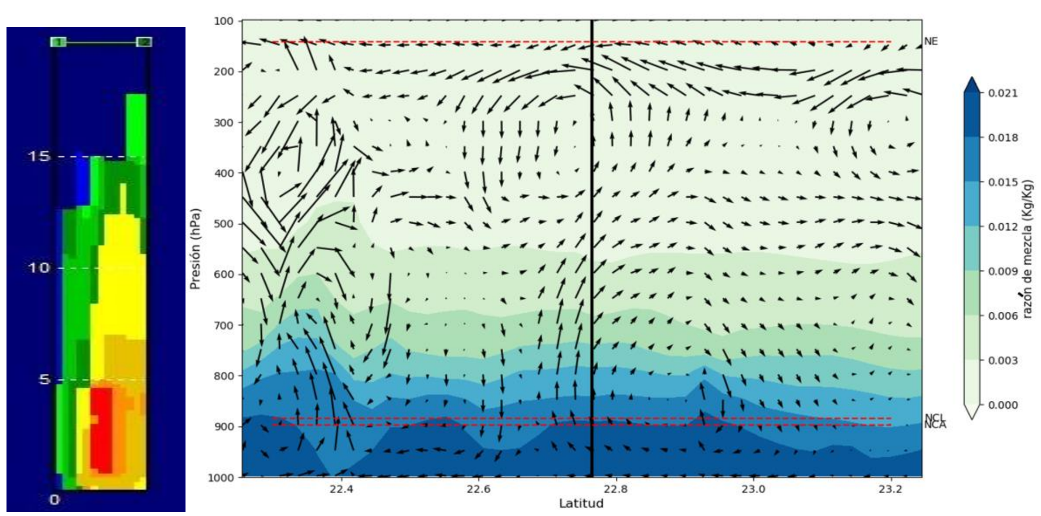
High relative humidity values at low levels are a necessary condition for deep convection and even for severity within it (Carnesoltas *et al*., 2013). This variable represented well the cells that produced the locally intense rain, showing columns of air with values higher than 90% from low levels to 200 hPa (Figure 8). This was more representative in the case corresponding to July 3 at Colón town, which registered the highest accumulated precipitation.



(a) **(b)**

Figure 8. Southern vertical slice of relative humidity from the WRF for (a) July 2, 2016 at 2300 UTC and (b) July 3, 2016 at 2100 UTC (b). The vertical line represents the latitude at which the storms occurred.

Some of the convective cells that generated the locally intense rain had updrafts that exceeded the 200 hPa level, even the 150 hPa level. This accounts for the penetrating caps observed in satellite images in the visible channel and the height of the maximum caps in radar observations (Figure 9). The speeds reached by the updrafts were between 5 m/s and 12 m/s, and by the descending currents between -2 m/s and -5 m/s. These values were higher than those obtained by Armas (2016) on his analysis of locally intense rain under anticyclonic influence.



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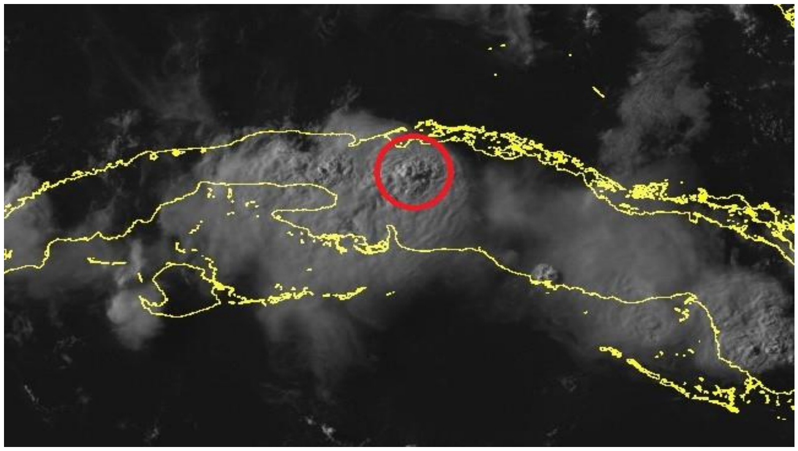
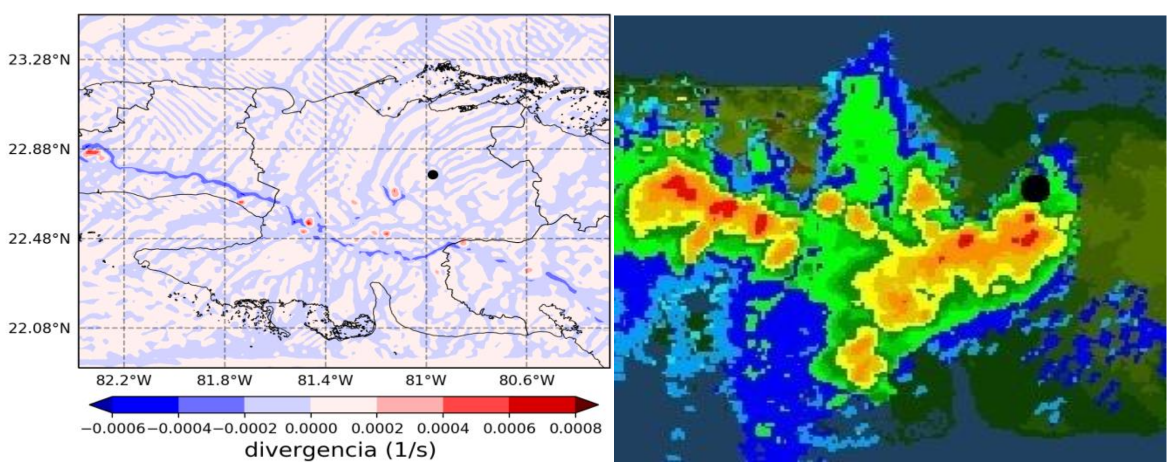


(c)

Figure 9.(a) Radar observation, (b) southern vertical section of the mixing ratio (kg/kg) with the wind direction from the WRF and (c) satellite image (visible channel), corresponding to July 3 2016 at 2200 UTC.

The divergence represented very well the breeze front and the streak fronts of the storms (Figure 10) and their values ranged between -0.003 1/s and 0.005 1/s. In the graphical outputs of this variable, it was possible to see areas where negative divergence, that is, convergence, between the breeze front and the predominant flow occurred. Small circular areas with positive values were appreciated that indicated the place where the downdrafts of the cells interacted with the surface and created a divergent flow that only converged at the border of the gust fronts that were generated precisely by this interaction.



(a) **(b)**

Figure 10.(a) Surface divergence from the WRF and (b) radar image corresponding to July 3, 2016 at 2200 UTC. The black dot represents the latitude and longitude at which the storms occurred.

CONCLUSIONS

1. From the RAP model it can be seen that the presence of the BFSs generates an unstable synoptic environment and potentially favorable for the development of deep convection, with vertical temperature gradients greater than 6.7×10^{-3} (ºC/m) in hours in the afternoon between the surface and the level of 500 hPa. The CAPE shows extreme values above 6000 J/kg close to the center of the system and the LI reaches -13. Furthermore, the relative vorticity at the 200 hPa level oscillates between 2.5×10^{-3} s^{-1} and 3.9×10^{-3} s^{-1} in the right sector of the BFSs, while the vertical speed describes upward movements to the south and east. of the system with values between -1.97 Pa/s and -3.76 Pa/s.

2. The wet BFS is characterized by being more intense than the dry one and, although the direct influence of both increases the temporal distribution of rainfall in Cuba, it is higher with the wet BFS. The highest accumulated are reported near the center of both systems. The highest number of reports of locally intense rain occurs in the western region of the lowlands, with three of the four cases, behavior similar to that of other dangerous phenomena such as TLS.

3. According to the output of the WRF model, the cases of intense rain are generated in an environment of weak vertical wind shear in the middle and lower troposphere, being moderate to strong in the upper troposphere. High relative humidity values greater than 70% predominate in the surface layer-800 hPa and a dry layer between 700 and 300 hPa with values lower than 45%. The temperature in 500 hPa ranges between -6 and -10 ° C and the isotherm of 0 ° C is located above 600 hPa. As for the CAPE, it is above 2300 J/kg in the four cases, with an LI that varies between -5 and -10. Using the 1 km spatial resolution of the WRF model, upward velocities within the cloud that reached 24 m/s can be determined.

4. The interaction of the pre-existing storm gusts or sea breeze fronts with the Horizontalez HCR Convective Rolls constitutes the main trigger for deep and organized convection. The storms that are generated are characterized by presenting maximum reflectivity values greater than 50 dBz in the four cases analyzed, the stops are greater than 12 km in height, exceeding 19

km in two of the cases and the height of the maximum reflectivity oscillates between 3 and 5 km. In all cases, the locally intense rain is generated by the influence of several convective cells. The Batabanó case is affected by four cells, while Colón and La Sierpe by five and three respectively.

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