

1 Proceedings

2 Analysis of possible physical factors that accelerate downdrafts 3 in storm clouds over Cuba†

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16 **Abstract:** One of the manifestations of Severe Local Storms is strong linear winds, which are known
17 as a downburst, capable of causing great losses to the country's economy and society. Knowing
18 which factors in the atmosphere are necessary for the occurrence of this phenomenon is essential
19 for its better understanding and prediction. The objective of this study was to analyze the possible
20 physical factors that accelerate downdrafts in the storm clouds in Cuba. To do it, 10 simulated study
21 cases simulated with the Weather Research and Forecasting (WRF) model at 3 km of the spatial
22 resolution were used. The factors capable of discriminating between downbursts and thunder-
23 storms without severity were obtained. These are, the absorption of latent heat by evaporation and
24 fusion, the equivalent potential temperature difference between the level of maximum relative hu-
25 midity in the low levels and of minimum relative humidity in the middle levels, the speed of the
26 downdraft, and the Downdraft Available Convective Potential Energy (DCAPE). Unlike previous
27 research, they discriminated against updraft buoyancy and energy advection, both at the middle
28 levels of the troposphere.

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32 1. Introduction

33 Severe Local Storms (SLS) are considered one of the most dangerous phenomena on
34 the mesoscale. The need to predict them has increased in recent decades, in an attempt to
35 mitigate the major socio-economic impact, they often cause, including the loss of human
36 lives. One of the manifestations of severity in the SLS is the strong horizontal linear winds
37 (greater than or equal to 25 m/s) observed along a line that moves through the land surface
38 called the Gust Front. This air mass is due to the cold downward current of the storm
39 cloud, known as downbursts (DB) [1].

40 The prediction of DB in Cuba continues to be a task of great interest for specialists.
41 The prevention of its occurrence is very complex since it affects a very small area and its
42 onset, development, and dissipation can occur in a short time. Knowing what pre-existing
43 factors in the atmosphere are necessary for this phenomenon to occur, especially in tropi-
44 cal island conditions, is essential for its better understanding and better prediction.

45 Numerous studies have been carried out around the world on DB, most of them to
46 achieve a more effective prediction of them. Doswell [2] findings are among the most im-
47 portant to consider. These show that liquid water content and negative buoyancy due to
48 the cooling by evaporation, are key factors that initiate and maintain a downward current.
49 Srivastava [3] also stated that among the factors that make possible the strengthening of
50 the downdraft is advection of relatively dry air with the consequent cooling by evapora-
51 tion and the reinforcement by a large amount of liquid water per unit volume. A study
52 performed by Caracena and Maier [4] for South Florida also stands out the importance of
53 dry air in the middle levels of the troposphere, as an environment that produces humid
54 Micro-downbursts (Micro - DB). Recently, Oreskovic [5], carried out an investigation from
55 numerical simulations of a DB taking into account a parametric study and a comparison
56 with a meteorological model. Furthermore, Burlando [6], carried out a study of a DB using
57 Laser Imaging Detection and Ranging (LIDAR) measurements and the modeling of the
58 cumulonimbus cloud (Cb) from the Weather Research and Forecasting model (WRF).

59 The first research carried out in Cuba about SLS was climatological, highlighting the
60 studies of Alfonso [7] and Aguilar [8]. Afterward, Aguilar [9] and Carnesoltas [10] focused
61 their research on finding the conditions that favor the occurrence of SLS in Cuba on a
62 synoptic scale. Carnesoltas [11] referred to three necessary conditions and one sufficient
63 for the occurrence of manifestations of local severity as a set of cause-effect processes, and
64 not as threshold values of independent variables.

65 Specifically, Gutierrez [12] determined the pre-existing physical-meteorological fac-
66 tors in the tropospheric mean levels that allow the occurrence of DB in Cuba. This author
67 used the Rapid Refresh Weather Numerical Forecast Modeling System (RAP), which has
68 13.5 km of spatial resolution. According to the author, this resolution is not ideal for
69 mesoscale work because produces difficulties in representing the physical processes that
70 generate DB. For this reason, was necessary to use a higher spatial resolution, which
71 would allow having a better detail of the pre-existing physical factors in the environment,
72 where the storm that could produce the severe event is going to develop. Therefore, the
73 objective of this study was to analyze the possible physical factors that accelerate
74 downdrafts in storm clouds in Cuba with a model of better resolution spatial.

75 2. Material and Methods

76 2.1 Region of study and selection of the cases analyzed

77 The study region included the entire Cuban territory since reports of DB and non-
78 severe Thunderstorms (TS) from different provinces of the country were analyzed. For
79 this selection was taken into account that Cuba is affected by various meteorological sys-
80 tems during the rainy and dry periods, which on many occasions are associated with TS
81 with severity and without it. The geographical distribution of the 10 cases selected for this
82 research is shown in Figure 1. The red points represent the DB, which was obtained from
83 the SLS reports in the Centro de Pronósticos del Instituto de Meteorología de Cuba
84 (INSMET), taking into account that no other severe event occurred this day. The blue
85 points correspond to the TS considering days and hours close to the DB reports so that
86 changes in the terrain or seasonal variations will not influence the results.

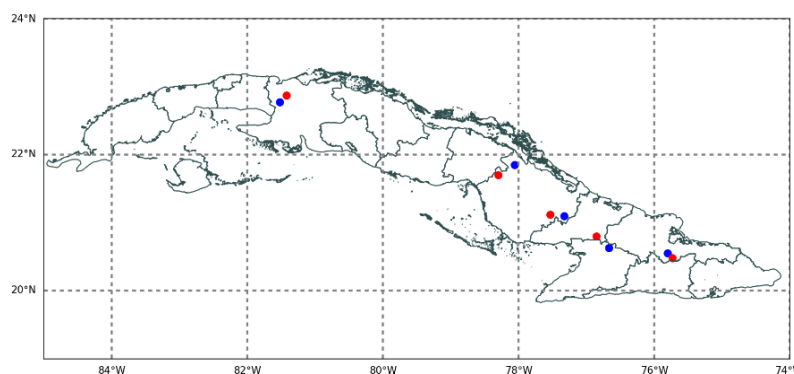


Figure 1. Geographical distribution of the storms analyzed. Red dots represent storms that produced downbursts and blue dots represent thunderstorms.

2.2 Data

The numerical outputs of the atmospheric model were used, WRF [13], version 3.8.1, initialized with the output of the Global Forecast System (GFS) model, with 0.5 degrees of spatial resolution and the dynamic core Advanced Research WRF (ARW). These outputs have a time resolution of 1 hour. The configuration used is shown in Table 1; in bold appears the specific characteristics of the domain used (3 km). This resolution permitted more details of the pre-existing physical factors in the environment where the storm developed.

Table 1. WRF model configuration.

Parameters	Configuration
Spatial resolution	27, 9 and 3 km
Number of points in x	145, 262, 469
Number of points in y	82, 130, 184
Vertical levels	28, 28, 28
Domain center	21.8° N y -79.74° W
Time step	150 s
Microphysics	WSM5, WSM5, Morrison double moment
Cumulus	Grell-Freitas, Grell-Freitas, no activated
PBL	Mellor-Yamada-Janjic, Mellor - Yamada-Janjic, Mellor -Yamada-Janjic

2.3 Methodology

The numerical outputs of the WRF with 3 km of the spatial resolution were used as a new tool to more accurately determine the position of the downdraft and to identify the significant physical factors existing in the atmosphere that could accelerate the downdrafts within the downdraft cloud storm. Specifically, the atmospheric pressure, potential temperature, geopotential height, the components of wind speed (u, v, w), and the mixing ratio of water vapor, cloud, rain, and ice were used. The cubic spline method was used to interpolate the variables at the corresponding latitude and longitude of each position of the storm. The equations of the dynamic and thermodynamic variables that were used to calculate the possible factors that were able to discriminate between the occurrence or not of DB are shown in Table 2, following the methodology proposed by Gutierrez [12].

Table 2. Physical formulas of the different dynamic and thermodynamic variables used to calculate the possible discriminating factors.

Variable	Formula	Possible discriminating factor
Latent heat	$\Delta Q_L = L \cdot \Delta m_a$	Absorption of latent heat by evaporation and fusion
Equivalent potential temperature	$\theta_{eq} = \theta + \left(\frac{L_v \cdot \theta}{C_p \cdot T} \right)$	Equivalent potential temperature difference (dry layer in the middle levels of the troposphere)
DCAPE	$DCAPE = g \int \frac{\theta_{vp} - \theta_{ve}}{\theta_{ve}}$	Dry layer in the middle levels of the troposphere
Buoyancy	$\frac{F}{M} = \frac{\theta_{ve} - \theta_{vp}}{T_{ve}} g = B$	Increased buoyancy in the updraft
Precipitable water	$d_w = \frac{r_T}{g \cdot \rho_l} \cdot (P_1 - P_2)$	Increased water load
Dynamic viscosity	$\mu_0 \frac{T_0 + C}{T + C} \left(\frac{T}{T_0} \right)^{\frac{3}{2}}$	Decrease in viscosity
Kinematic viscosity	$\nu = \mu / \rho$	Decrease in viscosity
Coriolis vertical component	$A_{cz} = 2\Omega u \cos\varphi$	Coriolis vertical component with an eastern flow
Horizontal advection of energy	$Adv_e \frac{\left(\frac{\rho_p \cdot w^{2d}}{2} \right)}{\partial z}$	Decrease in horizontal advection of energy
Horizontal advection of mass	$Adv_m \frac{\partial \rho_p}{\partial z}$	Decrease in horizontal mass advection

In addition, the speed of the downdraft was determined, from the DCAPE [14], using the following formula:

$$w_{maxd} = \frac{-\sqrt{2DCAPE}}{2}$$

The vertical speed of the downdraft was used to combine it with the factors mentioned above, to carry out a specific analysis of each one, and to be able to determine whether or not they managed to discriminate between the occurrence of DB. To do it is utilized methodology presented by Gutierrez [12].

The results obtained for the downburst of April 27, 2017 and the thunderstorm of April 30, 2017 will be presented. The selection criterion was based on the representativeness of the same where the differences of both phenomena are evident.

3. Results and Discussion

The factors related to viscosity, precipitable water, Coriolis vertical acceleration, and horizontal mass advection, failed to discriminate between the occurrence of DB and TS, coinciding with that obtained by Gutierrez [12]. One of the causes of these results may be related to their small order of magnitude, making a minimal contribution to the acceleration of downdrafts. It can even be considered that they are not able to discriminate between the two storms, since, despite the use of a higher spatial resolution, the results do not differ from previous research.

The most satisfactory results correspond to those related to the existence of the dry layer in the middle levels of the troposphere and the consequent absorption of latent heat by evaporation and fusion, ratifying what was obtained by Gutierrez [12]. Next, Table 3 is presented, which shows all the variables that we're able to discriminate between the occurrence of DB and TS, each with its respective possible critical values.

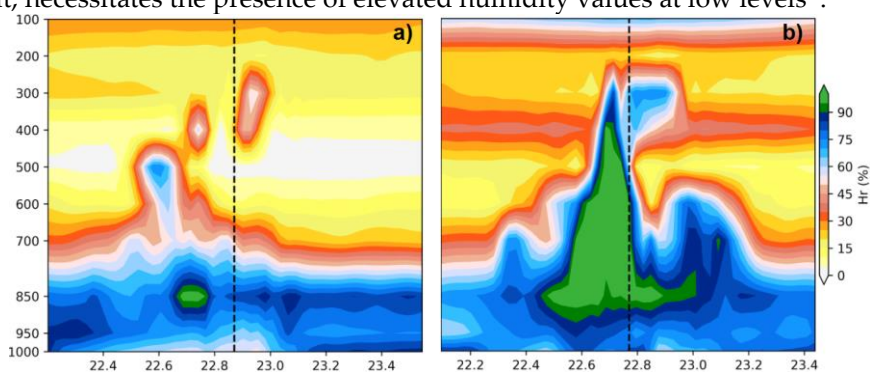
Table 3. Possible critical values of the variables that can discriminate between the occurrence of DB and TS. Latent heat absorption by evaporation, latent heat absorption by fusion, the equivalent potential temperature difference between the level of maximum humidity in the low levels and minimum humidity in the middle levels, buoyancy.

Date	Type	$\Delta Q_{LE}(J)$	$\Delta Q_{LF}(J)$	$\Delta\theta_{eq}(K)$	$B(m/s^2)$
27-04-2017	DB	47766.23	6346.72	14.73	0.1429
01-07-2017	DB	48338.42	6435.03	11.99	0.1572
20-07-2017	DB	41797.15	5562.41	12.19	0.1376
21-11-2017	DB	39596.14	5269.84	15.05	0.1133
14-05-2019	DB	32799.18	4364.37	8.99	0.1345
30-04-2017	TS	12749.92	1688.76	6.30	0.0456
03-07-2017	TS	30537.16	4064.28	1.68	0.1002
18-07-2017	TS	27030.77	3587.75	6.48	0.0828
23-11-2017	TS	24607.77	3277.13	4.62	0.0869
13-05-2019	TS	21510.58	2860.20	3.08	0.0785
Possible critical value		32000	4200	8	0.11

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For the analysis of the dry layer, zonal and southern vertical cuts of the relative humidity for the location of each of the storms were made. In both cases, there was a high moisture content in the low levels up to approximately 700 hPa, reaching humidity values that ranged between 75 and 100 % (figure 2). This result agrees with previous findings of Carnesoltas [11], who suggested that “the formation of deep convection, and even severity within it, necessitates the presence of elevated humidity values at low levels”.



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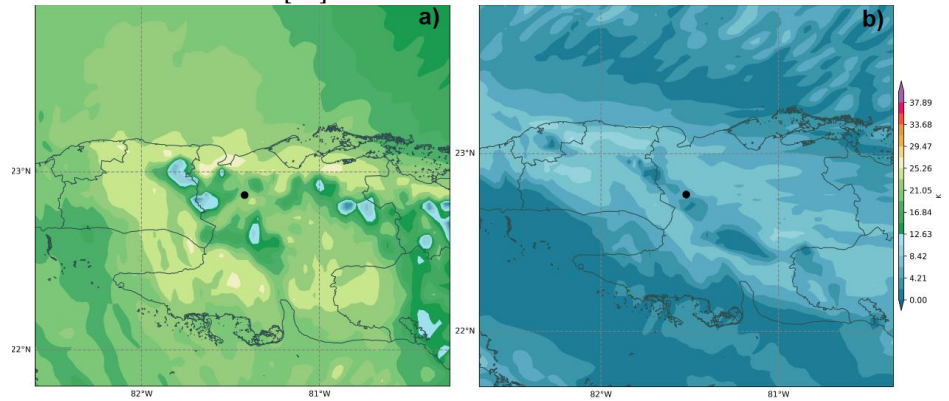
Figure 2. Cross section of relative humidity in latitude from the numerical outputs of the WRF. a) 27 April, 2017 (DB) and b) 30 April, 2017 (TS).

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The difference between both days was observed mainly in the middle levels of the troposphere, approximately between 700 and 400 hPa. In the case of DB, there was a deep dry layer at the aforementioned levels, with relative humidity values below 20%. However, in the case of the TS, the relative humidity reached higher values in the average levels, even reaching 100%, as shown in Figure 2, in the other cases they ranged between 35-50%. The low values of relative humidity in the middle levels of the troposphere, in the case of DB, favored the absorption of latent heat by evaporation and fusion mentioned before. This caused the air surrounding the water particles to cool down, become denser, with higher specific gravity, and accelerate toward the surface, helping to strengthen the downdraft.

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In addition, the spatial fields of the equivalent potential temperature difference between the level of maximum relative humidity in the low levels and of minimum relative humidity in the middle levels were analyzed. DB tended to be located in places where this difference was higher concerning TS, which can be seen in Figure 3, confirming what was obtained by Gutierrez [12]. This variable is representative of the humidity contrast that is generated in the case of DB [15].



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Figure 3. Equivalent potential temperature difference fields from the numerical outputs of the WRF. a) 27 April, 2017 (DB) and b) 30 April, 2017 (TS).

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The advection of energy in the average levels, the speed of the downdraft, and the DCAPE discriminated for all the cases analyzed, except for the DB that occurred on 21 November 2017, as shown in Table 4. This could be because it occurred in the dry season of the year. This can influence the behavior of the variables, as well as the conditions present in the atmosphere that allow the occurrence of this severe event. In addition, the departures available for this day correspond to 2000 UTC, which has a difference of 40 minutes concerning the time of the report, which may condition that the conditions have not been fully formed. That is why it is recommended that more cases of the dry season of the year be used in other investigations to analyze the behavior of the variables in this period.

Table 4. Possible critical values of the variables that can discriminate between the occurrence of DB and TS. Energy advection, downdraft velocity, DCAPE.

Data	Type	Adv _e (nm)(10 ⁻³ J/s)	wDCAPE(m/s)	DCAPE (J/kg)
27-04-2017	DB	62.50	48.62	4727.8
01-07-2017	DB	30.34	44.65	3986.69
20-07-2017	DB	36.77	36.33	2640.2
21-11-2017	DB	147.19	34.52	2382.71
14-5-2019	DB	54.96	36.18	2618.66
30-04-2017	TS	123.86	30.22	1826.79
03-07-2017	TS	74.17	33.19	2203.25
18-07-2017	TS	79.59	35.97	2587.93
23-11-2017	TS	124.28	27.82	1547.9
13-05-2019	TS	131.09	34.47	2375.98
Possible critical value		70	36	2600

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Unlike the results obtained by Gutierrez [12], the buoyancy and horizontal advection of energy, both in the middle levels of the troposphere, discriminated between the occurrence of DB and TS, as can be seen in Figure 4. Except for the DB energy advection of 21

November 2017, which presented $2.03 \cdot 10^{-1}$ J/s, and whose possible causes were raised above. The increase in buoyancy in the updraft contributes to a greater amount of mass rising in the case of DB, which makes it possible to also increase the amount of mass that descends, while the decrease in the horizontal advection of energy allows more flow to return to the surface, thus increasing the speed of the downdraft in both cases. It is considered that the resolution used in this investigation was related to these results, since it determines a better detail of the physical processes that take place within the storm cloud.

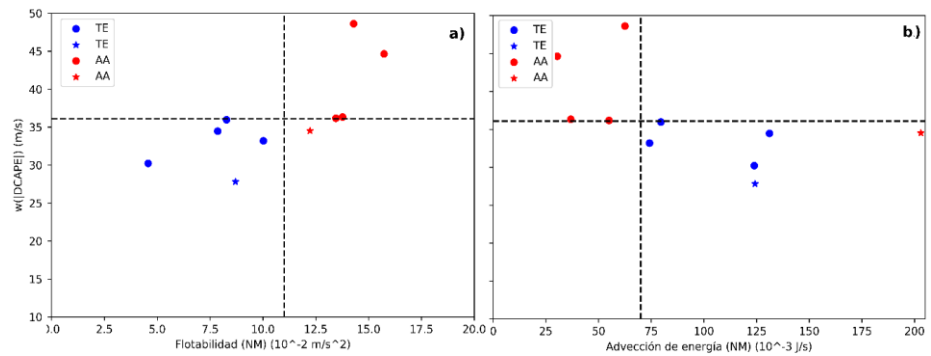


Figure 4. Relationships between: a) buoyancy and vertical speed; b) horizontal advection of energy and vertical velocity.

4. Conclusions

The factors that discriminated between the downbursts and thunderstorms without severity for different study cases in Cuba were determined. For all the cases analyzed, these are the absorption of latent heat by evaporation and fusion, both in the updraft, the buoyancy at the mean levels, and the equivalent potential temperature difference between the maximum humidity level in the low levels and the minimum humidity level in the middle levels. Unlike previous research, buoyancy and energy advection, both in the middle levels of the troposphere, were identified as discriminating factors between the occurrence of downbursts and non-severe thunderstorms. Viscosity, precipitable water, Coriolis vertical acceleration, and horizontal mass advection, although contributing to the acceleration of downdrafts, were not able to discriminate between the occurrence of downbursts and thunderstorms without severity, due to the order of magnitude so small that they have compared to the rest of the factors. The downbursts of 21 November 2017 did not comply with the critical values established for the horizontal advection factors of energy in the medium levels, the speed of the downdraft and the DCAPE, being able to be related to the time of the exit used and to belong to the dry season of the year.

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