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Proceeding Paper

Tropospheric Patterns Associated with Cold Fronts that Generate Heavy Rainfall in Cuba and Their Relationship with the NAO †

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Abstract: Cold fronts (CF) are the meteorological systems that affect the country in the dry season, which when combined with other meteorological conditions or local factors can generate precipitation, which is sometimes greater than 100 mm in 24 h. Some studies have analyzed the synoptic patterns associated with cold fronts that generate heavy rains in Cuba and the internal structure of these patterns. Similarly, from the 1990s, studies associated with the behavior of the North Atlantic Oscillation (NAO) teleconnection event within the winter period and the systems that are developed in it increased. However, the incidence of this event in the cold fronts that generate intense rains in Cuba in the winter period 1980–981 to 2016–2017 has not been taken into account. For this, the tropospheric patterns associated with these winter systems were identified, the behavior of this event was characterized in those winter seasons with intense rains and the mean field of temperature, humidity, wind and its derivatives associated with these meteorological systems when they generate rains intense and its relationship with said teleconnective event. The results obtained show that the NAO teleconnective event in the study period showed preference to be negative. The temperature, the relative humidity, and the fields derived from the wind presented homogeneity in the two phases of this event.

Keywords: cold front; heavy rains; synoptic patterns; NAO

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1. Introduction

The winter period or period with little rainfall in Cuba includes the months from November to April and is defined by the changes that occur in meteorological variables such as pressure, wind direction and speed, temperature, the presence of hydrometeors and in some cases severe events, with the passage of cold fronts. These meteorological systems are the most important in our country after tropical cyclones, not only because of their frequency but also because of the significant impacts they cause when combined with other meteorological conditions, including local factors and one of them is heavy rains (accumulated 100 mm in 24 h or less).

But it was not until 2019 that the phenomenon of heavy rains associated with cold fronts was studied with a link of meteorological variables and synoptic conditions, when Rodríguez-Acosta E. [1] in his research identified the synoptic patterns associated with cold fronts that generate heavy rains in Cuba. However, in this research, the author did not take into account the relationship that this meteorological situation could have with the behavior of the North Atlantic Oscillation (NAO), which significantly influences the winter period in the Northern Hemisphere and is vital in the assessments for a seasonal forecast.

How does the NAO affect cold fronts that generate heavy rains in Cuba? It is the scientific problem to be solved and for this, the general objective is: to determine the behavior of the NAO in the synoptic patterns associated to cold fronts that generate intense rains in Cuba. In order to respond to the same, the specific objectives are as follows: To identify the mean synoptic patterns in the lower, middle and upper troposphere, associated with cold fronts that generate heavy rains in Cuba; to characterize the behavior of the NAO in those winter seasons with heavy rains associated with cold fronts in the Cuban archipelago and its influence on them; to determine the mean field of temperature, humidity, wind and its derived fields, associated with cold fronts that generate heavy rains and its relation with the teleconnective event NAO.

The research is aimed at increasing knowledge about the relationship between heavy rainfall associated with cold fronts and its relationship with the NAO. Its results are of great importance and interest for meteorologists, particularly in the field of Synoptic Meteorology, Weather Forecasting and Climatology-Synoptics, due to the knowledge and contributions it provides in these areas, which have a greater weight in the services that contribute to the country's security.

2. Materials and Methods

The present study is based on the synoptic patterns that generate intense rainfall associated with cold fronts in Cuba defined by the author in [1] for each region of the country (West, Center and East), because these systems present different characteristics in each of them and their main fields are deformed as the system advances eastward over the Cuban territory. The geographical environment ranges from 15° N to 70° N and from 110° W to 10° W, because it is representative in the study of the circulatory patterns associated with the FF that affect the Cuban archipelago and the influence of the teleconnection events.

For the preparation of the final sample of circulatory patterns, only those months in which the most representative patterns by region and those that are repeated at the national level were taken into account.

The NAO index, according to Hurell [2], is based on the difference in standardized sea level atmospheric pressure anomalies between the stations located in Lisbon (Portugal) and Stykkisholmur (Iceland), since these stations are located closest to the mean position of the centers of action associated with this teleconnective event, and therefore more accurately reflect the meridional gradient between the two barycenters. Hurell [2], Fonseca [3] and Acosta [4] propose that as a general rule, values greater than 1 and less than −1 are considered to characterize the positive and negative phase of the index, respectively.

3. Results and Discussion

When analyzing the tropospheric patterns selected for this research, complying with the previously mentioned criteria, it was possible to appreciate that some of them coincided in months and year, so the final sample is made up of 33 months.

Of these, three months corresponded to the positive phase, representing 9.1% of the total number of months, while 5 months corresponded to the negative phase, which is more representative than the positive phase with 15.2%; the remaining 25 months corresponded to the neutral phase of this oscillation. Figure 1 shows the monthly absolute frequency of each of the phases of this oscillation in the study sample. The positive phase of this event is more frequent in the month of December with two cases and in the month of November only one case, while in the rest of the months it is in its neutral phase. The negative phase of this oscillation is most representative in the month of February with two episodes, while in the months of December, January, March and May the frequency was zero and in the remaining months only one case.

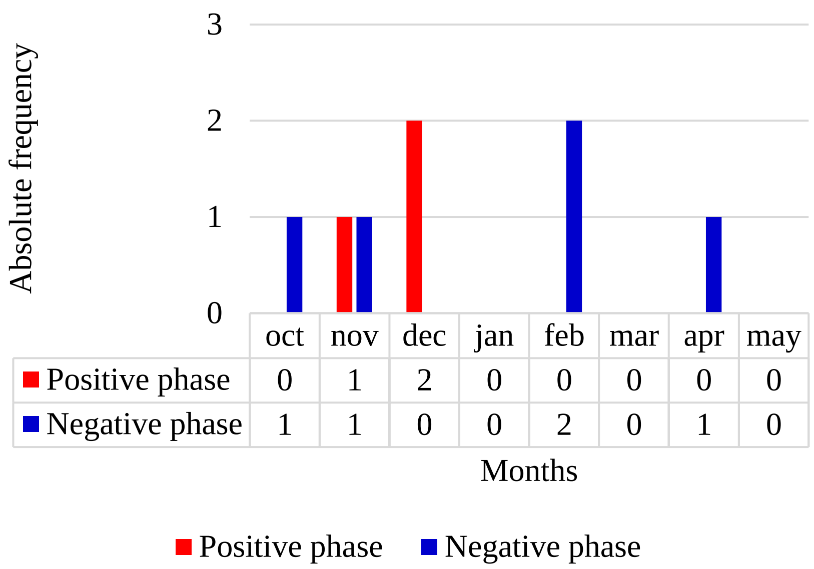

Figure 1. Absolute monthly frequency of each of the NAO phases in the study sample.

3.1. NAO Behavior by Tropospheric Patterns

3.1.1. Short Wave Trough Pattern Associated with Surface Cold Front

Figure 2 shows the short wave trough pattern associated with a surface cold front, in which the NAO was mostly in its neutral phase and the positive phase was only present in 16% of the cases, with the anticyclone having the highest pressures and the Icelandic low having the lowest.

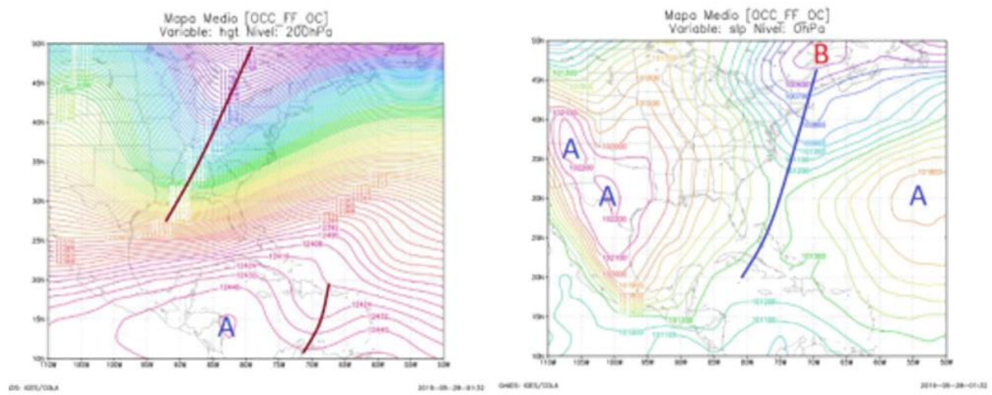

Figure 2. Short wave trough pattern associated with surface cold front.

3.1.2. Long Wave Trough Pattern Associated with Surface Cold Front

In the long wave trough pattern associated with a surface cold front, the NAO was in its neutral phase in 54 % of the cases in which any of its phases were present, these were manifested indistinctly, which means that the Icelandic low and the Azores anticyclone showed a weakening or intensity; this pattern is shown in Figure 3.

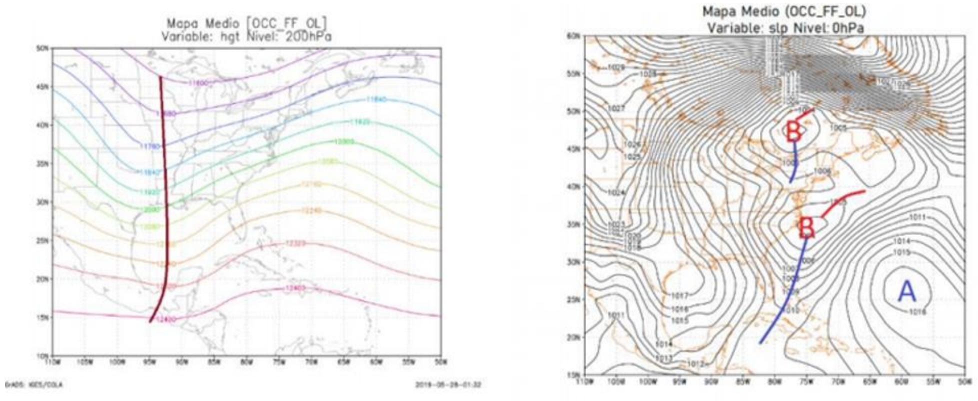

Figure 3. Long wave trough pattern associated with surface cold front.

3.1.3. Long Wave Trough Pattern Associated with Frontal Trough at the Surface

Figure 4 shows the long wave trough pattern associated with frontal surface trough. In this pattern, this oscillation was mainly in its neutral phase, although its negative trend was manifested in 24%, so the Azores anticyclone is weak and the Icelandic cyclonic cell is not very active.

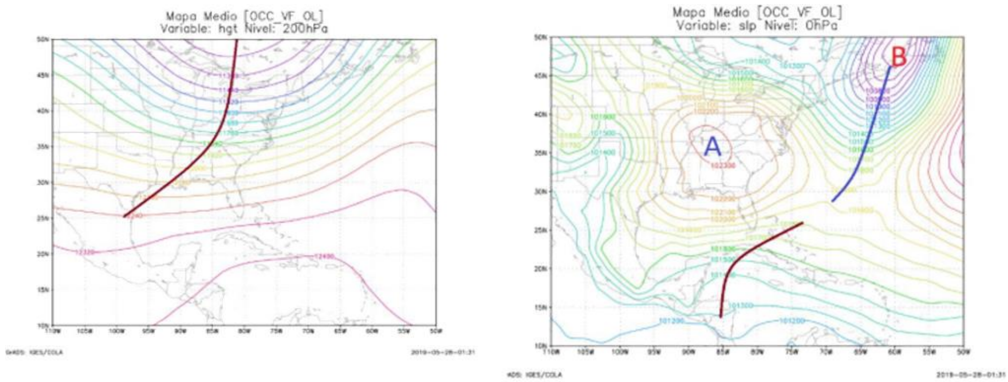

Figure 4. Long wave trough pattern associated with frontal surface trough.

3.1.4. Short Wave Trough Pattern Associated with Frontal Trough at the Surface

In the short wave trough pattern associated with a frontal trough on the surface (Figure 5), the NAO was less present in its negative phase, causing a weakening of the Azores anticyclone and the Icelandic cyclonic cell is not very active.

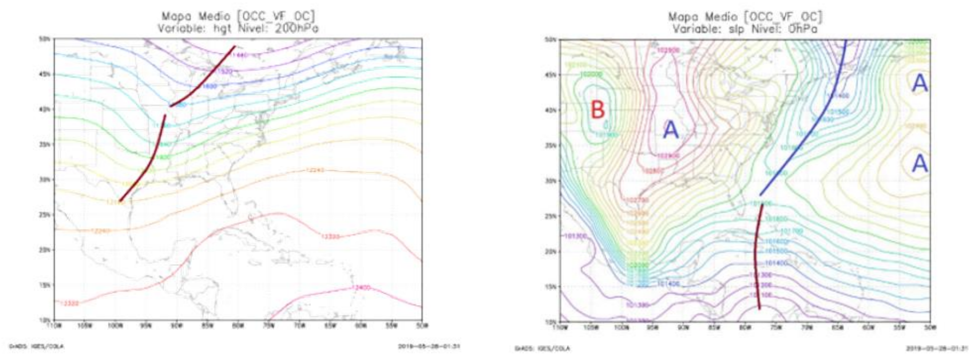

Figure 5. Short wave trough pattern associated with frontal surface trough.

3.2. Behavior of Meteorological Variables in Each NAO Phase

The determination of the variables temperature, relative humidity, wind and their derived fields are closely linked to atmospheric instability and the variable precipitation in order to identify the synoptic background conditions that could have led to the occurrence of heavy rain associated with cold fronts and their relationship to this teleconnective event.

3.2.1. Positive Phase

The temperature field at 850 hPa had a mean value of 15 °C, the cell with the maximum thermal value was located west of Mexico, in the vicinity of the Pacific Ocean. Relative humidity in the 1000–700 hPa layer was above 50% with a mean value of 58%, the cell with the maximum value was located over Mexico. The wind in its southern component was predominantly negative, with values that did not exceed 3 m/s, at 300 hPa the average value was −1.3 m/s and at 200 hPa it decreased to −0.6 m/s. Vorticity at 700 and 500 hPa presented negative values with mean of $-1.0 \times 10^{-5}s^{-1}$, respectively, with maximum values in the vicinity of Florida. Divergence was positive, with mean value of $6.6 \times 10^{-8}\ s^{-1}$ at 700 hPa, while at 500 hPa it was $4.3 \times 10^{-8}\ s^{-1}$, at both levels the maximum divergence value was over the Gulf of Mexico.

3.2.2. Negative Phase

As in the positive phase, the average thermal field was 15 °C, not exceeding 17 °C; the maximum values in the region were located over the Mexican territory. Relative humidity was between 52 and 60%, with an average value of 57% and the maximum values located over the Gulf of Mexico. The zonal wind component in the upper levels of the troposphere was mostly positive, with maximum values of 9 m/s; a mean of 0.3 m/s at 300 hPa and at 200 hPa, the mean value increased to 1 m/s. Vorticity was negative and divergence was positive. The mean value of vorticity at 700 hPa was $-1.1 \times 10^{-5}s^{-1}$ and at 500 hPa $-1.2 \times 10^{-5}s^{-1}$, the maximum values at both levels were located in the Gulf of Mexico. The average divergence at 700 hPa was $1.6 \times 10^{-7}s^{-1}$, increasing at 500 hPa to $3.2 \times 10^{-5}s^{-1}$, the maximum value cells were over the southern United States.

4. Conclusions

This study achieved the proposed objectives and led to the following conclusions:

1. The most significant synoptic pattern associated with cold fronts generating heavy rainfall in the period 1980–81 through 2016–17 is related to a frontal trough at high altitude, with shortwave amplitude, followed by the pattern of a cold front generated by a longwave trough.
2. The NAO teleconnection event in the period studied showed a preference to be negative.
3. The mean values of temperature in both phases of the NAO were 15 °C, the mean values of wind and vorticity behaved inversely proportional to the phases of the NAO. However, the divergence was positive in the positive phase and negative in the negative phase of the oscillation.

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