ECAS 2022

MDPI

Proceeding Paper

Analysis of SisPI Performance to Represent the North Atlantic Subtropical Anticyclone †

Jaina Paula Méndez [1], Maibys Sierra Lorenzo [2] and Pedro González Jardines [2,*]

[1] National Forecast Center, Cuban Meteorology Institute; jaina991123@gmail.com
[2] Atmospheric Physic Center; maibyssl@gmail.com
* Correspondence: pedro.met90@gmail.com

† Presented at 5th International Electronic Conference on Atmospheric Sciences, 16–31 July 2022; Available online: https://ecas2022.sciforum.net/.

Abstract: In this research, the performance of the Short-range Forecast System (SisPI by its acronym in Spanish) to represent the North Atlantic subtropical anticyclone over the parent domain during the 2020 wet season is evaluated. For this, an average of 2010–2019 decade was calculated using data from the ERA5 reanalysis at different levels of the troposphere for variables geopotential height, relative humidity, temperature and wind, in order to characterize the main systems that disturb the weather in the study area, to obtain the corresponding anomalies and to determine if the errors have more influence of these anomalies or SisPI configuration. For this it was necessary to interpolate SisPI data for make match with the resolution of ERA5 reanalysis and to be able to perform the calculations and generate the maps, for which a Python code was designed. The results suggest that SisPI shows tendencies to locate the high geopotential areas further south of its real position, which produces modifications in the synoptic flow forecasted. On the other hand, the northern and southern borders of the domain have the largest errors, mainly to the north, where, according to the decadal mean and the anomalies obtained in 2020 tends to generate a more baroclinic zone which creates an additional noise over said border. To the south it lies on segments of the ITCZ which may also be the reason for additional sources of errors on the model.

Keywords: SisPI; North Atlantic subtropical anticyclone; 2020 wet season

Academic Editor: Anthony Lupo

Published: 14 July 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

1. Introduction.

On wet season Cuba has mostly regulated by The North Atlantic subtropical anticyclone regime, while in the dry season, migratory anticyclones of continental origin are more predominant. Several authors affirm that the Bermuda-Azores High system has changed in the last decade, (Laings & Evans, 2016) [1] mentioned an expansion of the Hadley cell from 2 to 4° latitude grades since 1979, causes the position of its limits to have shifted to the poles, and displace arid zones, deserts and subtropical jets. Likewise, (Yang et al., 2020) [2] the variations and trends of the tropical width were explored from a regional perspective and they found that the width of the tropics closely follows the displacement of oceanic midlatitude meridional temperature gradients (MMTG), where show that enhanced subtropical warming leads to poleward advance of the MMTG and drives the tropical expansion. In this sense, (Fernández et al., 2021) [3] obtains, using the 1981–2010 climate norm, a greater adjustment of variables (atmospheric pressure, temperature and precipitation) with the NAO (Atlantic Oscillation North) and the AO (Arctic Oscillation), even in the wet season with increasing values in the last decade (2009–2018) and also increased in his research that in that decade a westward expansion of the subtropical ridge in all months of the year, especially in the lower and middle levels of the troposphere. Due to the impact that these changes may have on Cuba weather, it is of interest to evaluate their behavior for the improvement of the numerical modeling systems, in particular the Short-range Forecast System (SisPI), operated by the Atmospheric Physics Center of the Cuban Institute of Meteorology. This Short-range system has been evaluated and made the obtained results report by (Sierra et al., 2014) [4], where combined three microphysics and three cluster parameterizations for two nested domains of 27 and 9 km spatial resolution, in addition to (Sierra et al., 2017) [5] conducted sensitivity studies of the SisPI to changes in the PBL, the number of vertical levels and the microphysics parameterizations and clusters, at very high resolution. However, no studies have been conducted to determine if its representation of synoptic scale system is correct.

2. Materials and Methods

The SisPI is the Short-range system that makes predictions based on the Weather Research and Forecasting (WRF) model and it has three domains of 27, 9 and 3 km of resolution, where the parent domain is approximately between 31° and 12° north latitude and west longitude between 97° and 61°. It contains Central America and the Caribbean Sea, where it is possible to forecast meteorological systems at a synoptic scale, that is why it was taken as a study area of this research.

To analyze behavior of SisPI forecast at parent domain, the data from the ERA5 reanalysis (extracted from https://climate.copernicus.eu/climate-reanalysis) establishing a comparison by studying the geopotential height, relative humidity, wind and temperature at mandatory levels, where it was taken as analysis of 2020 wet season. Firstly, from ERA5 reanalysis, the mean maps of these variables were obtained for 2010–2019 decade to determine the position of the main synoptic systems, including the North Atlantic anticyclone subtropical and thus verify the changes referred to by the antecedents. Later, proceeding to the analysis of 2020 wet season, the average maps of the anomalies in comparison with the decadal average to determine the greatest changes with respect to the last 10 years. Regarding the SisPI data, the error was calculated with respect to the ERA5 values of 2020 wet season and together with the analysis of the anomalies, the possible reasons for said errors were analyzed.

3. Results y Discussion

3.1. Decadal Characterization of the Fields Obtained from the ERA5 Reanalysis between 2010-2019

The results obtained by the antecedents suggest that in the last decades the North Atlantic anticyclone has experienced an expansion of its dorsal and relative changes in relation to its strength and usual position. These variations seem to be more evident in the middle and lower levels of the troposphere, as well as in the last decade, which is why at first its behavior was analyzed in this investigation based on the mean values of the ERA5 reanalysis for the height variables geopotential, relative humidity, wind and temperature in the period 2010–2019. With the obtaining of these average maps, interesting characteristics could be appreciated: At the 1000 hPa level, it is evident that the mid-position of the subtropical ridge extends to the Gulf of Mexico throughout 2020 wet season, coinciding with the expansion described in (Fernandez et al., 2021) [3].

At middle levels of the troposphere, at beginning of the study period, it was observed that the axis of the May-June seasonal trough was moving further east, causing the area of maximum vorticity advection of the trough was found in the central and eastern regions of the territory, while the driest portion was located in the west. These changes in geopotential fields, they were also appreciated in the relative humidity fields at this level. On May the driest values on the island were over the west of the country and the wettest extended along the central and eastern regions, coinciding with the zone of maximum vorticity advection cyclone of the trough. These reasults indicated that the beginning of the wet season was delayed on Cuba's western region. (Figure 2). Continuing with middle levels analysis on summer months, like what was obtained by (Fernández et al., 2021) is observed the establishment of a belt of high geopotential values close to the Tropic of Cancer region, suggesting an interaction between the Mexican and the subtropical ridge. This fact could be the cause of limited exchange between tropic and mid latitudes.

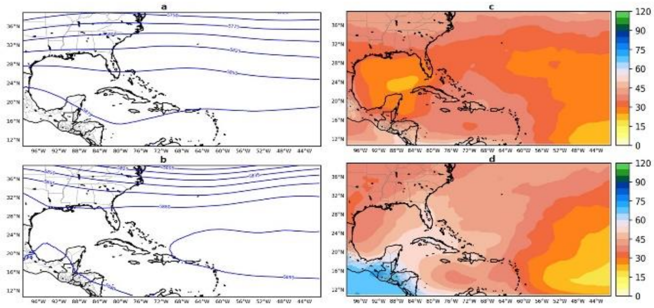

Figure 1. Mean geopotential height maps at the 500 hPa level on May (**a**) and June (**b**), with their respective relative humidity maps (**c**) and (**d**) for 2010-2019 decade.

The least significant changes happen at 200 hPa, since the mean position of tropical upper tropospheric trough (TUTT) remains with little variation in the last decade. It can be seen from 2 that TUTT relative position, according to the isohypses coincides with a thermal trough that establishes a closed cold center on mean temperature map located northeast of Hispaniola in July. This average cold core could be because formation of cold lows, which tend to fall off the TUTT, often causing severe weather, as these upper troughs spawn cold-core depressions aloft called TUTT cells, which produce clouds deep convective and precipitation tending to be south and east of the trough, as shown in Figure 4b.

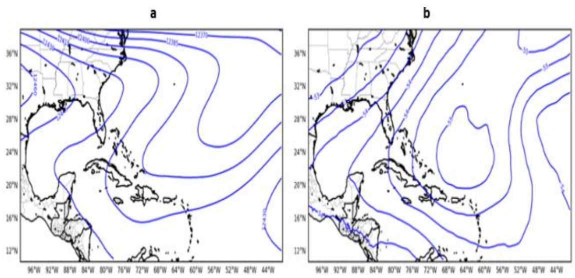

Figure 2. Mean geopotential height maps (**a**) and teperature (**b**) at 200 hPa level in July from ERA5 reanalysis for 2010–2019.

3.2. 2020 WET Season. Anomalies Compared to Decadal Average

When analyzing the average anomalies maps of 2020 wet season respect to those average decade of the ERA5 reanalysis, the greatest changes were observed in the transition months, mainly in May, where positive anomaly values were found in the range between 15–60 m^2/s^2, mainly east of the −88° meridian, with a maximum located northeast of the Southern Bahamas (Figure 5b). Towards the sectors that comprise the Gulf of Mexico and continental America, null variations of the geopotential fields are observed, although their intensity decreases slightly (−15 m^2/s^2) over central portions of Mexico. This could be associated with a strengthening of high geopotential values due to an expansion of the subtropical ridge in high levels, which corresponds to the temperature anomalies obtained, around 1 °C (Figure 5c), generated by heating due to diabatic compression associated with the anticyclone that generates heating of the air layers in the atmosphere. In the analysis of the anomalies behavior in the wind field it was possible to appreciate (Figure 5d) that the speed of the wind increases, with values between 20–40 km/h towards the north of the 24° parallel area, coincided with the region of greater warming, which suggests a certain direct relationship between the behavior of both variables, which could lead to a southward extension of the subtropical jet stream, which may lead to in somewhat more baroclinic environments in the tropical zone. Although the average position of the May-June trough led to a decrease in the days with rain, especially towards the west, these baroclinic environments could generate favorable conditions so that the local instability lead to severe weather manifestations. This fact, although not proven by studies of national specialists it has been observed and documented in recent years by specialists and amateurs.

In addition, an anomalous anticyclonic circulation centered on the mean wind map stands out approximately over Hispaniola which may be in response to the expansion of the subtropical ridge and the consequent formation of secondary anticyclonic circulations in the region of the periphery of the same. Towards portions where negative anomalies are observed in the geopotential fields, can verify that these coincide with a cooling in high levels and a decrease in the wind force.

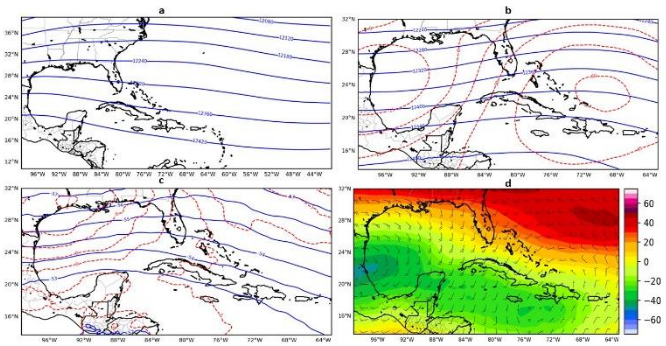

Figure 3. ERA5 Mean geopotential height maps for May 2020 at the 200 hPa level; (**a**) decadal mean for said month and (**b**), the correlation between the values obtained for 2020 (blue) and the anomalies compared to the decade (red). (**c**) shows the mean map of the temperature anomalies and (**d**), the mean map of wind anomalies for the same level in that month.

For middles levels, on May and June the anomalies did not exceed 25m^2/s^2, whose maximous values are located near from Hispaniola and Puerto Rico. These results confirm the presence of the May–June trough with a very similar structure to that observed in the average decadal analyzed before, however, there may be a slight displacement to the west.

At low levels, the behavior was similar to that previously explained, but to a lesser extent than at levels related to the upper air. In particular, 2020 June was quite similar to the behavior studied in the decadal mean for close to the surface levels. For the following two months at 200 hPa level, the same trend persisted, however, a slight increase in the geopotential that suggests a TUTT contraction, fundamentally in the tropical zone. When analyzing the average temperature map for July 2020, the cold nucleus to the southeast of the TUTT persists, however, to the north of Puerto Rico, entering the Atlantic, it appears a core of warm anomalies, which appears in response to a further southerly shift of said cold core.

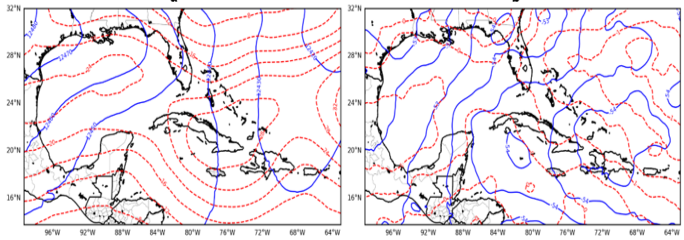

Figure 4. ERA5 Average maps of geopotential height (**a**) and temperature fields (**b**) at 200 hPa level on July. Relationship between the obtained values in 2020 (blue) and the abnormalities compared to the decade (red).

For these months, in average levels the belt of high geopotential values persisted caused by the subtropical ridge expansion, bringing with it the formation to the southern United States of a induced trough by the interaction of said dorsal with the Mexican, cause of the negative values in said area.

Another interesting result is found at the close to surface level for September and October, mainly in the geopotential and wind fields, associated with the active behavior of 2020 cyclonic season that generated a decrease in the values of these two variables.

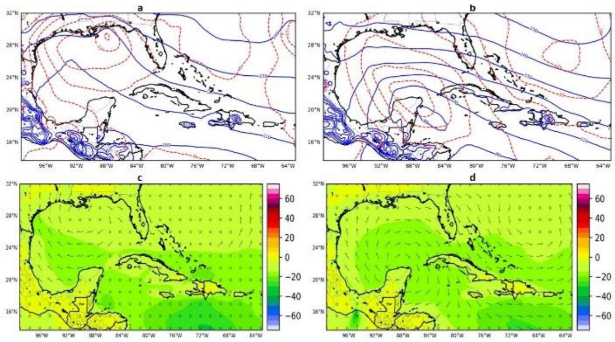

Figure 5. Mean maps of geopotential (**a**) and wind (**b**) fields anomalies at the 1000 hPa level on September (**left**) and October (**right**).

3.3. Analysis of the 2020 Wet Season Represented by SisPI. Errors Respect ERA5 Results

The study of the anomalies was useful to later understand better the analysis of obtained errors from SisPI, because both coincided that were higher at beginning and ending of wet season, which is consistent with the stages of transition towards summer in May and towards winter in October, where tropical and mid-latitude systems interact. These situations can be uncertainties sources for the model, however, it became necessary to determine if the errors of the SisPI forecast in the wet season of study depend on these anomalies or on its own configuration. Also the errors were softened more in the months of June to August, where summer conditions are well established and performance did not vary greatly from decade. According to what was obtained, SisPI has the particularity that the northern border of the external domain is located right in the region where the positive geopotential anomalies were, in addition to the greater warming and greater discontinuities of relative humidity. This leads to greater gradients of the meteorological fields and, consequently, a error source on the northern border. On the other hand, the interaction with the Intertropical Convergence Zone (ITCZ) is located south of the domain, and discontinuities have also been observed in the meteorological fields, although less than to the north.

The errors at 200 hPa were greater in the northern and southern borders of the domain with geopotential values similar in both with opposite signs, mainly on May, where they reach values up to 160 m^2/s^2, which suggests additional strengthening of the equatorial trough related to the ITCZ to the south and high pressure areas to the north (Figure 6a).

As can be seen in Figure 6b, this geopotential behavior coincides with temperature errors, being 2 to 4 °C overestimated to the north while, on the contrary, an additional cooling of up to 4 °C difference is appreciated to the south. However, wind field errors suffered an increase towards the southern border of the domain in relation to the speed in approximate order of 30–40 km/h (Figure 6c), while towards the northern border the average wind forecast was weaker than actual by an order of magnitude of 20–40 km/h. This could imply that SisPI was not able to forecast the increasing trend of the more baroclinic conditions in the tropical zone, as well as the latitudinal descent of the subtropical jet, which has weight in the forecast of perturbed states in time that could lead to the occurrence of local severe storms (LSS).

These errors are smoothed out in the following quarter, progressively decreasing until reaching a minimum in July and begin to rise again from August. The most noticeable errors found in the relative humidity and wind fields. During these months SisPI generates a additional dryness at high levels. The specific cause of these results is difficult to determine because there are several factors that can influence this, for example, the vertical border is set at this level, the typical initialization errors and those derived from the parameterizations physics used by the model.

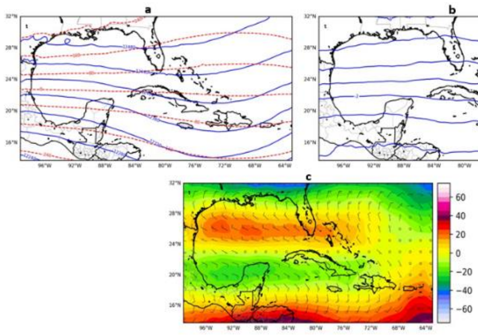

Figure 6. Mean SisPI error maps corresponding to the geopotential (**a**), temperature (**b**) and wind (**c**) at the level of 200 hPa for May 2020.

In case of TUTT behaviour, as can be seen in Figure 7a, SisPI predicted it to be somewhat more compressed as a result of positive errors in geopotential field, however, its adequate representation of the temperature fields could detect the cold core region localized over Hispaniola and adjacent seas, a fact that can be seen in Figure 7b).

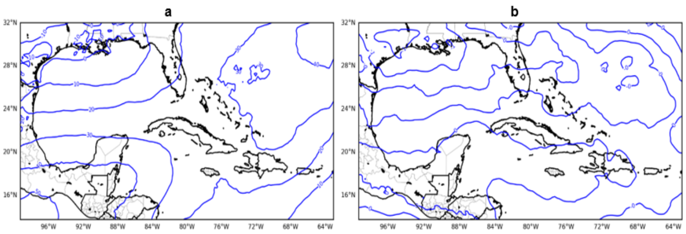

Figure 7. Mean maps of SisPI errors geopotential (**a**) and temperature (**b**) fields for July 2020 at 200 hPa level.

In September and October the model errors gradually increase on the northern and southern borders of the domain, reaching maximum values in October, which they do not become as high as in May, with the exception of the wind fields. Again SisPI represents well the temperature field at that level and the geopotential errors reach positive maximums in October above 120 m^2/s^2 towards the northern border, and negative maximums in sectors of the southern border of up to (-80 m^2/s^2) (Figure 8a). Regarding the wind the errors acquire characteristics similar to those described in May, although it is observed that they differ in magnitude. Particularly, in the month of October, greater errors are observed towards the western border, something that is not revealed in previous months and that suggests deficiencies when it comes to represent the characteristics associated with the Mexican ridge when the subtropical is in contraction (Figure 8b).

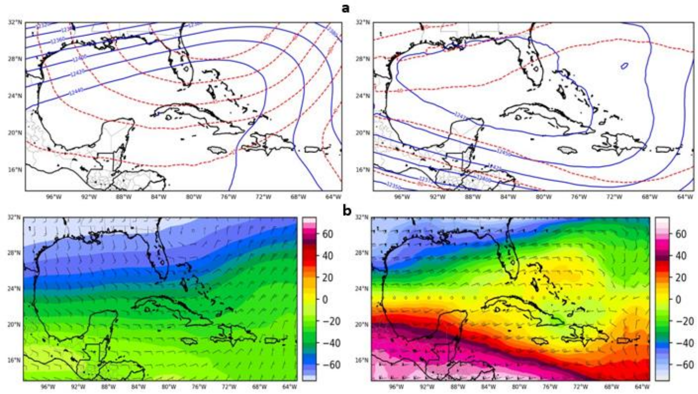

Figure 8. Comparison between the mean representation of geopotential (**a**) and wind (**b**) fields between ERA5 and SisPI at the level of 200 hPa on October 2020.

At medium levels, the errors had a similar behavior, being higher in May where, despite being less than the situation obtained on 200 hPa level, having values maximum of 80 m^2/s^2, SisPI fails in the representation of the sinusoidal flow since it shows a zone of dorsal, possibly in allusion to the Mexican in the region of the Gulf of Mexico and portions of the west from Cuba and the western Caribbean Sea and a trough area in the southeast quadrant of the domain. This representation is contrary to the average obtained for May 2020, which places the trough area and the ridge to the eastern border of the domain (Figure 9).

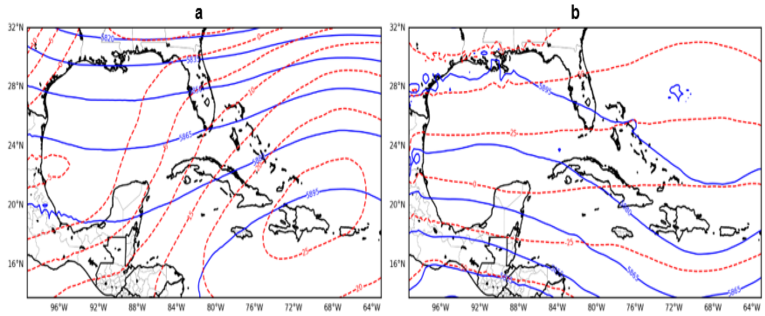

Figure 9. Comparison between the representation of the flow obtained by ERA5 (**a**) and that calculated by SisPI (**b**) corresponding to the month of May in 500 hPa.

Consequently, with the flow errors represented by SisPI, drier environments were generated in the western half of the domain, although in reality the trend was to decrease relative humidity, to exception of small portions of the Atlantic northeast of The Bahamas, where SisPI increases the humidity, probably related to the trough zone that it erroneously represented. The wind speed errors turned out to be insignificant in large areas of the domain and grow coincidentally with the largest localized warming regions over continental America in the upper left corner of the domain (~6 °C) and with the greatest cooling towards the lower left corner (~−6 °C). This has some implications for the SisPI forecasts, particularly in relation to precipitation, whose forecast accuracy has been one of the fundamental objectives of the work team since the creation of the system.

These dorsal conditions and drier environments, especially in the west, could lead to a increase in model failures on May. On June–August quarter the model makes a more realistic representation of the relative position of systems on middle layers, where represent quite accurately the belt of high geopotential values that arises at consequence of natural expansion of the subtropical ridge and its interaction with the Mexican, being the representation of this system the most prone to errors because it is located on west boundary of the domain. For September and October, negative errors were observed north of Antilles and positive in the central and eastern Caribbean Sea, because of deficiencies in the dorsal representation on upper air, characterized by a south displacement of its center of heights geopotential values, specifically in central and eastern of the Caribbean Sea. This causes errors on SisPI forecast much drier environments over the Caribbean Sea.

On 1000 hPa, a south relocation of regions of high geopotential value was observed for the month of May, specifically over the Caribbean Sea. Average flow predicted by SisPI differs from the original pattern, which places the areas of high geopotential values at the north of the Greater Antilles, imposing an almost zonal flow while SisPI represent a sotheast flow over Cuba. Despite this, the geopotential errors at this level are in the −60 to 60 m^2/s^2 order (Figure 10a).

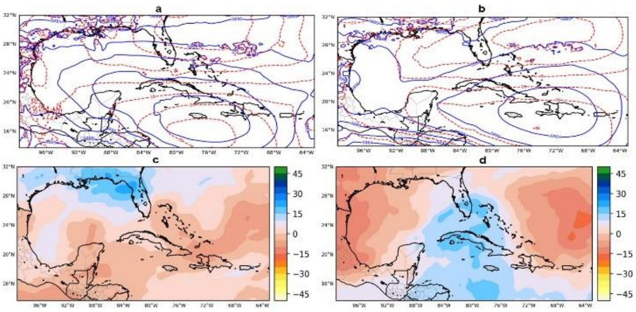

Figure 10. Average synoptic flow represented by SisPI in blue and the errors respect ERA5 data in red (**a**,**b**), with the humidity errors obtained (**c**,**d**) for September and October at 500 hPa level.

As a consequence of this, a drier environment is generated on Cuba, fundamentally by the west, which coincides with the previous reasoning, where it is exposed that SisPI represents inadequately the position of the Mexican dorsal and it is reaffirmed that this can bring negative consequences for precipitation forecast on this month.

In the June–August quarter, the results of the errors do not differ greatly from the characteristics observed at high and medium. Once again, it is corroborated that during the months of summer SisPI forecasts are usually realistic because stability conditions persists. In September and October there are an errors increase in the geopotential field, which have two fundamental causes: firstly, the change of position at south of the subtropical ridge at surface and, secondly, a faster contraction of the anticyclonic ridge, resulting in a greater decrease in the geopotential value in a large part of the domain, mainly in October (Figure 3.16). Relative humidity errors were not significant. In relation to the temperature it can detect an overestimation towards the northern border, this being one of the most domain problems. The forecast wind field also does not suffer from very significant errors, however, it stands out that on land the model tends to increase speeds, in the Antilles and Central America is where this statement can be seen in more detail.

4. Conclusions

1. SisPI tends to locate high geopotential areas south than its real position, which that produces modifications in synoptic flow.
2. Because of the deficiencies of SisPI to represent the correct position of the North Atlantic subtropical anticyclone, it tends to forecast a drier tropospheric column compared to the actual.
3. The northern and southern domain borders contain the largest errors, mainly at north, where, according to anomalies obtained in 2020, a baroclinic zone tends to be generated, which creates an additional noise on said border. At south it is on segments of the ZIC, which can also be the reason for additional model error sources.
4. The behavior of SisPI errors presents a maximum in May, then descends until reaching a minimum in July, rising again until reaching a second peak in October, which does it is less than the first month of the wet season. Corroborating that the mixture present in the transition months is very difficult to represent by the model.

5. The main errors seem to be more associated with their own configuration that with the anomalies obtained with respect to the decadal mean of the wet season analyzed.

5. Patents

Author Contributions:

Funding: This research received no external funding.

Institutional Review Board Statement:

Informed Consent Statement:

Data Availability Statement:

Conflicts of Interest: "The authors declare no conflict of interest."

References

1. Laing, A.; Evans, J.L. Version 4.0. Chapter Global Cirlculation. In *Introduction to Tropical Meteorology*; *The Comet Program*; IEEE: New York, NY, USA, 2016.
2. Yang, H.; Lohmann, G.; Lu, J.; Gowan, E.J.; Shi, X.; Liu, J.; Wang, Q. Tropical expansion driven by poleward advancing midlatitude meridional temperature gradients. *J. Geophys. Res. Atmospheres.* **2020**, *125*, e2020JD033158. https://doi.org/10.1029/2020JD033158.
3. Fernández, M.; González, C.M.; González, P.M. *Cambios en los Espectros de Algunas Variables Meteorológicas y su Relación con los índices NAO y AO*; Revista Cubana de Meteorología: La Habana, Cuba, 2021.
4. Sierra Lorenzo, M.; Borrajero Montejo, I.; Ferrer Hernández, A.L.; Hernández Valdés, R.; González Mayor, Y.; Cruz Rodríguez, R.C.; Rodríguez Genó, C.F. *Sistema Automático de Predicción a Mesoescala de Cuatro Ciclos Diarios*; INSMET, Centro de Física de la Atmósfera: La Habana, Cuba, 2014.
5. Sierra Lorenzo, M.; Borrajero Montejo, I.; Ferrer Hernández, A.L.; Morfa Ávalos, Yanmichel; Morejón Loyola, Yordanis; Hinojosa Fernández, Miguel. *Estudios de Sensibilidad del SisPI a Cambios de la PBL, la Cantidad de Niveles Verticales y, las Parametrizaciones de Microfísica y Cúmulos, a muy Alta Resolución*; Instituto de Meteorología, Centro de física de la Atmósfera, La Habana, Cuba, 2017.