A STUDY OF CYCLONIC ACTIVITY IN THE NORTH ATLANTIC FOR THE 2005 VERSUS 2020 SEASON

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Abstract
Over the last two decades, the North Atlantic ocean basin has experienced record-breaking hurricane seasons with regards to storm frequency and intensity. This short study examines the ocean and atmospheric characteristics of the two most active hurricane seasons on record, the 2005 and 2020 seasons. Accumulated cyclone energy, sea surface temperature, sea-level pressure and wind shear data in the main development region of the North Atlantic are compared between the two record-breaking seasons. Results of time series analysis show that 2005 was the hurricane season with the highest accumulated cyclone energy index, while 2020 was the 4th highest of 55 seasons analyzed. Results of spatial analysis of sea surface temperature anomalies exhibit that 2005 had a slightly higher average surface temperature than 2020 in the main development region of tropical cyclones, and that 2005 had higher temperatures in the central region of the study area while 2020 had higher surface temperatures in the southern Caribbean region. Comparisons between the sea level pressure anomalies show that 2005 had a slightly lower average pressure than 2020, with 2005 exhibiting lower anomalies in the northern area and 2020 showing anomalous pressure patterns in the eastern part of the main development region. When wind shear anomalies are examined, we found that 2020 had a lower average wind shear than 2005, a factor that could explain why 2020 had a higher number of tropical cyclones. Overall our results suggest that both 2005 and 2020 seasons had similar ideal ocean-atmospheric conditions for higher tropical cyclone activity.
Keywords: Tropical Cyclones; Hurricane Season; Climate Change; Accumulated Cyclonic Energy (ACE).

1. INTRODUCTION

The main development region (MDR) of the North Atlantic (NA) Ocean (10-20N, 20-80W) is one of the tropical regions of the planet where conditions for tropical cyclone (TC) formation are ideal, mostly between the months of June through November, which is considered to be the official hurricane season of the NA. Studies that have focused on the frequency and intensity of TCs in the NA have detected an increase in the number of major hurricanes (Cat 3 or higher) and also a rise in the total number of storms that formed outside of the official hurricane season months (Wang et al.,

2008; Knutson et al., 2010; Strazzo et al., 2013; Hernandez Ayala and Méndez-Tejeda, 2020). More recently, the 2020 hurricane season in the NA recorded the highest number of TCs (30) on record, a higher amount of TCs than the previous most active season 2005. This study examines and compares the oceanic-atmospheric characteristics of the two most active hurricane seasons on record, the 2020 and 2005 seasons.

The 2005 Atlantic hurricane season (figure 1) began on June 8 with Tropical Storm Arlene, and then things escalated rapidly. The first hurricane of the season was Cindy, which started on July 3, followed by Dennis on July 4, and then Emily on July 11. Both Dennis and Emily became major hurricanes, Dennis being the first hurricane of the season to hit hard, leaving destruction from the Caribbean Sea to the northern coast of the Gulf of Mexico, being responsible for 42 deaths: 22 in Haiti, 16 in Cuba and 3 in the United States. (Beven et al., 2008). During the 2005 hurricane season, a total of 15 tropical storms became hurricanes, exceeding 74 mph, tropical cyclones Katrina, Rita and Wilma reached Category 5, whose winds exceeded 156 mp on the Saffir-Simpson scale. This breaks a historical record of hurricanes in a single season, that was previously 12 hurricanes in 1969.

Before 2005, only two years (1960 and 1961) recorded two hurricanes reaching category 5 in the same season (Pasch et al, 2006). It was in 2005, where they recorded for the first time, four major (≥ 3) hurricanes (Dennis, Katrina, Rita and Wilma) making landfall in the United States (Beven et al., 2008). In this same year with 882 mb, Hurricane Wilma became the most intense hurricane ever measured (3). Previously, Hurricane Gilbert (888 mb), which struck Jamaica and the Yucatan Peninsula in 1988, had been the most intense hurricane, (Beven et al., 2008; Shein, 2006). Two other hurricanes in 2005, Rita (897 mb) and Katrina (902 mb), became the fourth and sixth most intense Atlantic hurricanes on record so far.

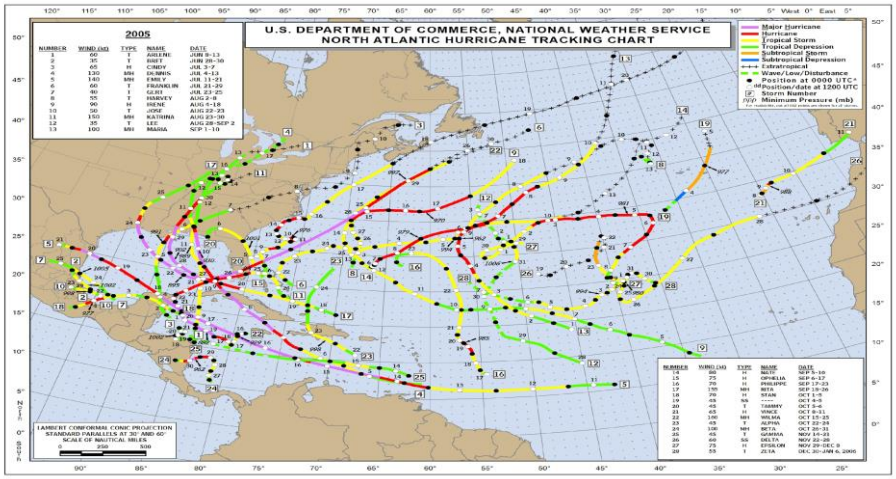

Figure 1. The figure shows the trajectory of the Tropical Cyclones for the 2005 hurricane season.

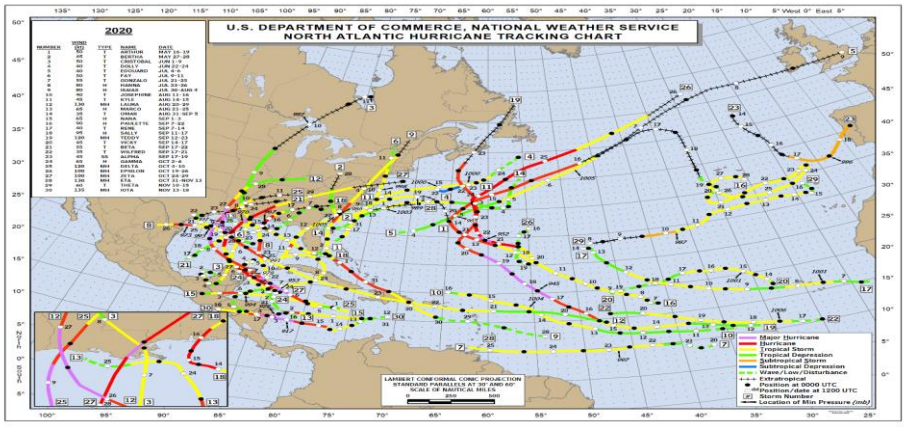

Figura 2. The figure shows the trajectory of the Tropical Cyclones for the 2020 hurricane season.

Tropical cyclone activity in the NA basin during the 2020 hurricane season was hyperactive, starting with May 19 with subtropical storm Athur and after finishing the selected holly-tree letters, it ended in the Greek alphabet with Hurricane Iota on November 13. The total number of tropical storms named this season broke the all-time record set in 2005, this can be seen as the most remarkable aspect. However, we also saw more examples of very fast intensification and very slow moving hurricanes, which have recently been linked to climate change (Bhatia, et al 2019; Wang, et al 2017 and Chan, 2019).

In 2020, there were ten notable hurricanes that intensified rapidly (Hanna, Laura, Sally, Teddy, Gamma, Delta, Epsilon, Zeta, Eta, and Iota), some of which underwent explosive intensification in a relatively short time, and two hurricanes that practically stopped moving when they made landfall in Central America (Sally on the Gulf Coast and Eta in Central America) Both hurricanes Eta and Iota made landfall in Nicaragua, in this case two major category hurricanes in almost the same location, causing extensive damage. In general, the 2020 Atlantic hurricane season (figure 2) was extremely active, with activity well above normal for the season. A record thirty named storms formed, of which thirteen became hurricanes and six became major hurricanes - Category 3 or higher on the Hurricane Saffir-Simpson wind scale.

In general, the 2020 Atlantic hurricane season (figure 2) was extremely active. A record thirty named storms formed, of which thirteen became hurricanes and six became major hurricanes - Category 3 or higher on the Hurricane Saffir-Simpson wind scale. There was also a tropical depression that did not reach enough strength to become a tropical storm. An important factor to note about the 2020 season is that La Niña conditions were weakening higher level winds, which enhances tropical cyclone development and intensification by allowing tropical convection with little disruption (Klotzbach et al., 2021).

2. DATA & METHODS

This short paper used Accumulated Cyclonic Energy (ACE), sea surface temperature (SST), sea level pressure (SLP) and vertical wind shear (VWS) data in order to compare and identify similarities or differences between the two most TC producing seasons in the NA Basin. ACE data were obtained from NOAA's Physical Sciences Laboratory (PSL) Working Group on Surface Pressure . The SST, SLP and VWS data were obtained from NOAA/ESRL Physical Sciences Laboratory and the National Center for Environmental Prediction (NCEP) reanalysis dataset .

Several studies (Villarini and Vecchi, 2013; Lin, et al, 2013; Scoccimarro, 2018; and Hernandez Ayala and Mendez Tejeda, 2020), have shown that the surface temperature of the ocean has been used as a significant predictor to investigate the relationship between the thermal state of the North Atlantic basin and TC activity in terms of the ACE. Other studies have also examined the relationship between SLP, associated with the weakening-strengthening of the NA high pressure system, and TC frequency and intensity and have also studied the connection between weaker VWS, associated with La Nina conditions, and higher late season TC activity in the NA basin (Latif et al., 2007; Ryglicky et al., 2018; Klotzbach et al., 2021)

A time series of the ACE index was constructed in order to compare the two most active seasons on record between them and the rest of the seasons in the post-satellite era (1966-present). SST, SLP and VWS anomaly plots for the hurricane seasons months of 2005 and 2020 were produced in order to examine the spatial characteristics of the ocean-atmosphere conditions. The anomaly plots of SST, SLP and VWS of 2005 were subtracted from the 2020 anomaly plots in order to identify spatial similarities or differences between the two record TC producing seasons.

3.RESULTS & DISCUSSION

Accumulated Cyclonic Energy (ACE).

The Accumulated Cyclonic Energy (ACE), is the measure of the total seasonal activity used by NOAA is the accumulated cyclonic energy. The ACE is an index of wind energy, defined as the sum of the squares of the maximum sustained surface wind speed (knots) measured every six hours for all named storms while they are at least tropical storm intensity. In a normal season, the ACE values are around 106, when the value of this index exceeds 170 it is considered that it is a hyperactive season.

Since 1966, the highest ACE index values correspond to 2005. In this year the recently revised index value was 250 with 28 named storms, 15 of them hurricanes, and 7 of them major hurricanes. The 2005 Atlantic season was an exceptionally active season when compared to all of the seasons that preceded that year and a very active year for US landfalling storms. The season that held the ACE record before 2005 was 1995 with a 228 ACE, that season also had a record number of named TCs with 19, 11 hurricanes and 5 major hurricanes. The numbers for the 2005 season are larger than the above-normal season averages for the MDR of 5.8 TS, 4.3 H, and 3 MH and well above the 1951- 2000 MDR averages of 4.6 TS, 3.2 H, and 1.9 MH. A record sixteen named storms also formed outside the MDR during 2005, resulting in six hurricanes and two major hurricanes. The ACE contribution from these 16 systems (130.5% of the median) far exceeded the previous season high of 80.8% set in 1959. During 2005,

these non-MDR systems accounted for 45.6% of the total ACE value, far above the average contribution during above-normal seasons of only 14.5% of the total.

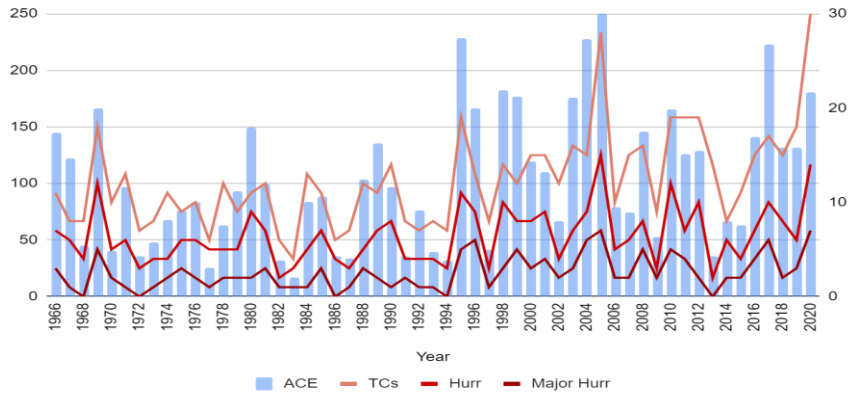

Figure 3. Accumulated Cyclone Energy index (ACE) and total number of TCs, Hurricanes and Major Hurricanes in the Atlantic Ocean from 1966 to 2020.

After 2005, the 2017 season exhibited the 3rd highest ACE index on record (224.9) with 17 named storms, 10 hurricanes, 6 major hurricanes 93 named storm days, 51.75 hurricane days, 19.25 major hurricane days. The 2017 hurricane season had three hurricane Category 4 hurricanes Harvey, Irma and Maria, which made landfall in the United States following 12 years without a major hurricane landfall in the country. Puerto Rico received more than 30 inches of rainfall in a 72 hour period, and two locations in southeastern Texas received more than 60 inches of rain from Hurricane Harvey, a new tropical cyclone rainfall record in the U.S. (Van Oldenborgh et al., 2017; Wand et al., 2018; Keelings and Hernandez, 2019; Hernandez Ayala and Méndez-Tejeda, 2021) Hurricanes Harvey, Irma and Maria combined to produce over a quarter-trillion dollars in damage in the U.S. Hurricane Irma was the longest-lived Category 5 hurricane on record in the Atlantic Basin since the beginning of the satellite era in 1966, maintaining that intensity for a total of 3.25 days, according to NOAA.

Even though the 2020 Atlantic hurricane season had the highest number of named TCs (30) on record, it ended up with an ACE index value of 184.5,quite well above the threshold for the 'extremely active' category yet below the ACE index values of the 1995, 2005 and 2017 seasons (Fig 3). Of all NA hurricane seasons in the post-satellite era, 2020 had the 4th highest ACE index. The lower ACE index for 2020 could be associated with a lower number of intense hurricanes when compared to the 2005 season. Since the ACE is an index that combines the numbers of TCs, their respective durations and their intensity, we can see that 2020 surpasses in the total number of storms metric, yet the duration and intensity factors were slightly lower for 2020 when compared to the 2005 and 2017 seasons. Without any doubt, the 2020 hurricane season in the NA basin was the most significant in total number of TCs and in developing the conditions for major hurricanes to develop late into the hurricane

season, yet in terms of ACE, it was surpassed by the 1995, 2005 and 2017 seasons (Fig 3).

Ocean-Atmosphere Patterns 2005 and 2020

Sea Surface Temperature

Since the 2005 and 2020 hurricane seasons in the NA basin produced the highest number of named TCs on record, this part of the study focuses on examining some of the oceanic-atmospheric characteristics of those seasons in order to identify spatial similarities or differences between them. When the SST anomalies in the MDR for the 2005 hurricane season in the NA basin are examined, we find that most of the area experienced above average SSTs (Fig 4a) with an MDR mean of 26.53°C. The area with the highest SST anomalies (>0.6°) for 2005 was found in the eastern Caribbean, in the area where most of the TCs, hurricanes and major hurricanes formed. The main cause of the anomalous SSTs in the MDR was a weakening of the northeasterly trade winds and a corresponding reduction in latent heat release from the ocean (Foltz and McPhaden, 2006; Saunders and Lea 2008).

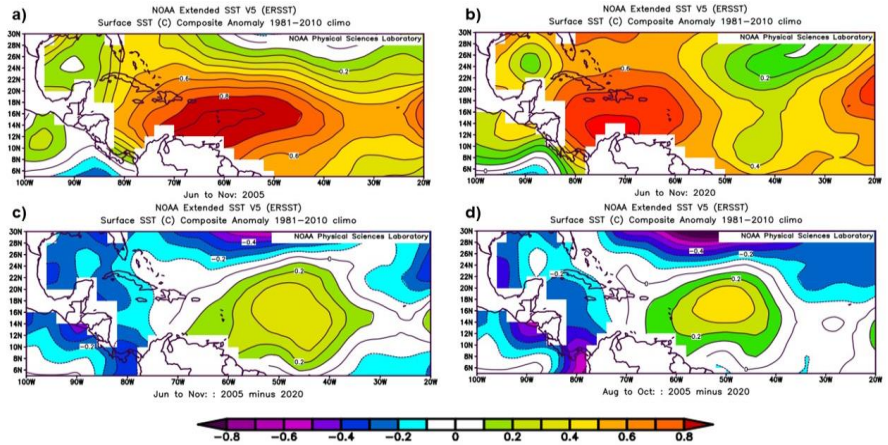

Figure 4. SST composite anomalies in the NA basin for the 2005 (a) and 2020 (b) hurricane seasons (June - November) and the difference in anomalies between 2005-2020 (c) and (Aug-November) 2005-2020 (d).

The 2020 hurricane season exhibited overall lower SST anomalies when compared to 2005 (Fig 4b) with an MDR mean of 26.49°C, yet higher SSTs were observed in the southern Caribbean where the late hurricanes Delta, Zeta, Eta, and Iota caused ample devastation in their path through various Central American Countries (Cite). When the averaged SST anomalies from 2005 are subtracted from 2020, we find that 2005 (2020) exhibited higher (lower) SSTs in an area east of the smaller antilles and that 2005 (2020) showed lower (higher) SSTs in the south and western Caribbean (Figure 4c, 4d). These results suggest that 2020 had a higher number of total TCs since the SSTs in the southern and western Caribbean remained higher than normal in the late hurricane season months (Oct-Nov) which led to late forming hurricanes that

increased the total amount of storms that formed in the season. Higher average SSTs in the Caribbean during the 2020 season produced ideal thermodynamic conditions that were much more favorable for storm activity, especially for late-season TC formation (Klozbach, 2021).

Sea level Pressure

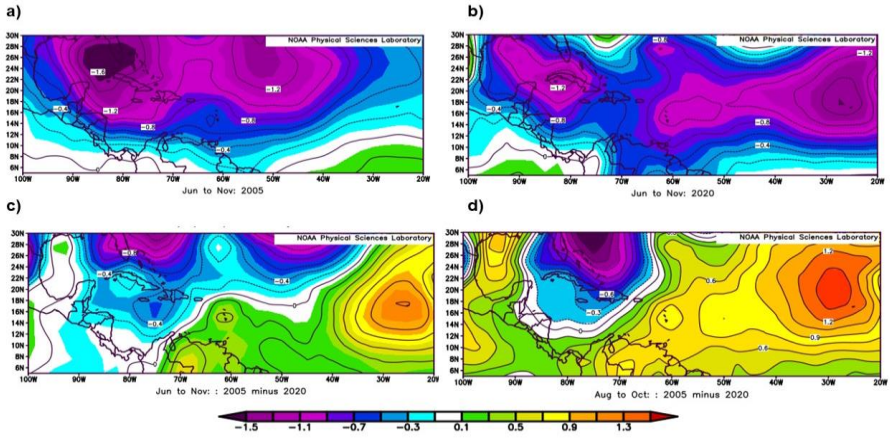

Figure 5. SLP composite anomalies in the NA basin for the 2005 (a) and 2020 (b) hurricane seasons (June - November) and the difference in anomalies between 2005-2020 (c) and (Aug-November) 2005-2020 (d).

Comparisons between the sea level pressure anomalies show that 2005 had a slightly lower average sea level pressure (1015.43 mb) than 2020 (1015.59 mb). The 2005 hurricane season exhibited lower anomalies in the northern area of the main development region, especially in the Gulf of Mexico. The SLP anomalies for 2005 show lower than normal pressure patterns in the areas where powerful hurricanes like Hurricane Katrina formed. The SLP anomaly plot for the 2020 hurricane season shows a wider area of below normal SLP in the MDR of the NA basin that corresponds to the region where most of the TCs formed in that season.

When the 2005 SLP anomalies are subtracted from 2020, we find that 2005 exhibited higher SLP patterns in the far eastern area of the MDR than 2020, yet 2005 showed lower SLP patterns in the western side of the MDR (Fig 5c). These SLP patterns correspond with the higher number of TCs that formed in the Gulf for 2005 and the higher number of TCs that formed in the eastern Atlantic and southern Caribbean regions in 2020. When the spatial subtraction is done between the peak hurricane season months of 2005 and 2020, we see that those SLP differences are even more pronounced. Overall, SLP anomalies covered a larger area in 2020 when compared to 2005.

Vertical Wind Shear

Comparisons between average VWS environments show that 2020 had a lower wind shear than the 2005 season. As noted by previous studies (cite), lower VWS environments tend to be associated with a higher frequency of TCs in the NA basin, which could be an important factor that could explain why the 2020 hurricane season produced 30 named TCs. The 2005 hurricane season exhibited higher VWS environments in the southern Caribbean and the Gulf of Mexico and lower VWS patterns in the northern part of the MDR (Fig 6a),

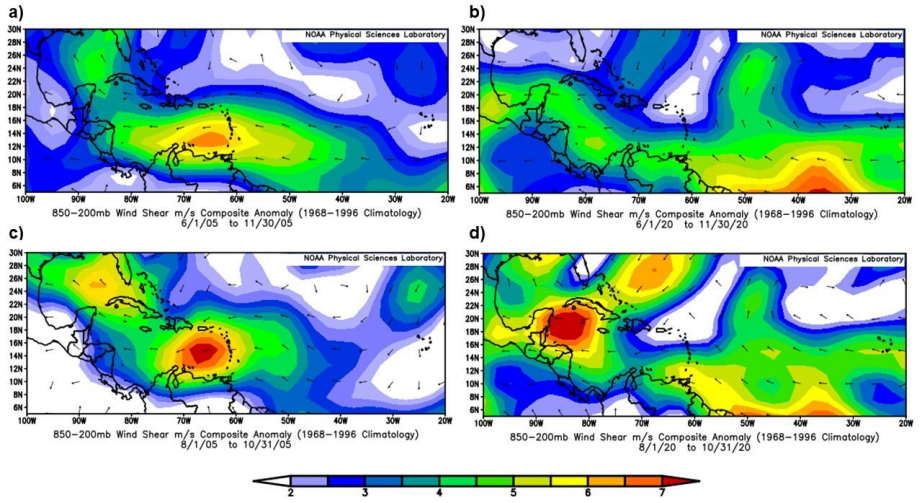

Figure 6. VWS composite anomalies in the NA basin for the 2005 (a) and 2020 (b) hurricane seasons (June - November) and the difference in anomalies between 2005-2020 (c) and (Aug-November) 2005-2020 (d).

On the other hand, the 2020 season shows higher VWS environments (Fig 6b) in the southeastern section of the MDR and along Central America, while lower VWS patterns were observed in the northern area of the MDR. These lower VWS patterns were associated with La Niña conditions. Overall, both the 2005 and 2020 seasons had lower than normal VWS environments, yet the 2020 season exhibited a larger area with below average VWS that could be associated with La Niña conditions that tend to promote higher TC frequency by weakening high atmospheric winds (Klotzbach et al., 2021). When the average VWS anomalies are examined for the more active hurricane season months, we see that the 2005 season exhibited higher VWS patterns in the southern Caribbean and lower VWS in the eastern MDR. The mean VWS environments for the more active hurricane season months of 2020 show higher VWS patterns in the western section of the MDR, while lower VWS is observed in the eastern area of the region.

4.CONCLUSIONS

The 2005 and 2020 hurricane seasons in the North Atlantic shared similar oceanic-atmospheric environments that made them the most active seasons on record. The 2005 season produced 28 named storms, of which # were hurricanes and # were major hurricanes, while the 2020 season had 30 TCs with # being hurricanes and #being major hurricanes. Both were extremely active hurricane seasons based on the accumulated cyclone energy (ACE) index, with 2005 ranking as the 1st and 2020 as the 4th highest ACE of 55 seasons analyzed.

Spatial analysis of sea surface temperature anomalies for both seasons shows that 2005 had a slightly higher average SST than 2020, with 2005 having higher SSTs in the Gulf and 2020 showing higher anomalies in the eastern section of the TC main development region. Sea level pressure anomalies show that 2005 had a slightly lower average pressure than 2020, with 2005 exhibiting lower anomalies in the northern area and 2020 showing anomalous pressure patterns in the eastern part of the main development region. We also found that 2020 had a lower average wind shear than 2005, which could be the main factor that could explain why 2020 had a higher number of tropical cyclones.

Overall our results suggest that both 2005 and 2020 seasons had similar ideal ocean-atmospheric conditions in the North Atlantic basin. Both seasons had ideal SST, SLP and VWS conditions that allowed for a high number of storms developing, with many of those becoming hurricanes. Both the 2005 and 2020 seasons had similar SST and SLP patterns, with only some spatial differences. However, average VWS was way lower in 2020 than in 2005, which was associated with La Niña dominant conditions in the MDR that could explain why 2020 surpassed 2005 in total number of named storms. Future research will focus on examining how the 2020 season compares with the 55 other seasons in the post-satellite era and if any climate variability or climatic change factors played a major role in making the most active on record.

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