Colombian Caribbean warming and the intensity of hurricanes between June and December 2020

El calentamiento del Caribe colombiano y la intensidad de los huracanes entre junio y diciembre de 2020

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Abstract

The Colombian Caribbean Sea had sustained surface water temperatures above 29 ºC between July and December 2020. The geographic statistics calculated for the Colombian Caribbean Sea, examined from thermal images of that season in the upwelling area of La Guajira, showed that these values exceeded the monthly averages and the average for the hurricane season, and had not been previously observed. These temperatures occurred during the development of hurricanes Eta and Iota, which reached categories 4 and 5 as they passed through the San Andrés Archipelago and Central America. The review of the climatology indicates that this condition occurred at the inverse peak of the El Niño (La Niña) phenomenon. During this condition, the surface wind regime inverts as the Chocó jet arriving from the west strengthens.

Keywords: sea surface temperature, 2020 hurricanes, Colombian Caribbean, upwelling, La Guajira.

Resumen

Valores de temperatura superficial del mar mayores de 29 ºC ocurrieron de manera sostenida en toda el área del mar Caribe colombiano entre julio y diciembre de 2020. La estadística geográfica desarrollada para el mar Caribe colombiano, examinada desde imágenes térmicas de dicha temporada en el área de surgencia de La Guajira, mostró que estos valores sobrepasaron las medias mensuales y la media estacional que corresponde a la temporada de huracanes, con valores que no se habían observado anteriormente. Dichas temperaturas ocurrieron durante el desarrollo de los huracanes Eta e Iota, los cuales alcanzaron categorías 4 y 5 en su paso por el archipiélago de San Andrés y los países centroamericanos. La revisión de la climatología, indicó que esta condición se presentó en el pico inverso del fenómeno El Niño (La Niña), durante la cual el régimen de vientos superficial se invierte en el sector, al aumentar el viento de chorro del Chocó que llega del oeste.

Palabras clave: *temperatura superficial del mar, huracanes 2020, Caribe colombiano, afloramiento, La Guajira.*

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Introduction

The formation and development of storms and hurricanes is related to different environmental variables, one of which is sea surface temperature (SST). Studies indicate that they are born around warm waters and weaken when they reach waters with cooler surface temperatures (Landsea, Bell, Gray and Goldenberg, 1998; Perlboth, 1967; Fisher, 1958). Other variables that come into play are atmospheric pressure, and wind vorticity and shear (Collins *et al*., 2016).

The process begins with a group of storms moving across the ocean surface. When the surface water is warm (>26 ºC), the storm absorbs the thermal energy of the water, thereby increasing the moisture in the air and lowering the atmospheric pressure at the surface. If wind conditions are right, the storm becomes a hurricane. This thermal energy is the fuel for the storm: the warmer the water, the more moisture in the air, which could mean bigger and stronger hurricanes (Cione and Uhlhorn, 2003; Latif, Keenlyside and Bader, 2007).

Estimates of heat content of the upper ocean and the energy extracted from it by a storm illustrate that relatively modest changes (on the order of 1 °C) in surface temperature at the inner core of the storm can indeed alter the total maximum enthalpy flux (sensible plus latent heat) by 40 % or more and that the variability associated with the change in SST at the inner core appears to be an important factor directly related to the change in intensity (Cione and Uhlhorn, 2003).

Saunders and Lea (2008) evaluated the contribution of SST to the increase in Atlantic hurricane activity in the period 1995-2005. They found that the sensitivity of hurricane activity to SST between August and September during the period evaluated was such that a 0.5 °C increase in SST is associated with a ~40 % increase in hurricane frequency and activity. They also found that local sea surface warming was responsible for ~40 % of the increase in hurricane activity relative to the 1950-2000 average between 1996 and 2005.

SST behavior in the Colombian Caribbean is dominated by the temperature acquired by the waters carried by the Caribbean Current, and its meanders and vortices, as it passes through the basin (Andrade and Barton, 2000) and is modified by the lower temperatures resulting from the upwelling process that occurs along the South American coast of Venezuela and Colombia, especially in the Cariaco and La Guajira areas (Muller-Karger and Aparicio, 1994; Andrade and Barton, 2005).

For these reasons, it is important in oceanography to monitor SST as a precursor to the development of storms in the region. For this purpose, satellite sensors are very effective, such as the MODIS spectroradiometer on board the AQUA satellite, which allows mapping from daily SST images obtained in a very precise way (National Aeronautics and Space Administration [NASA], 2022). The present study aims to examine the SST in the Colombian Caribbean during the hurricane season (June-December) of 2020, by monitoring the 26 ºC isotherm extracted from satellite images and comparing it with the average statistics for the area that were presented in Bernal, Poveda, Roldán and Andrade (2006) and the Atlas of Oceanographic Data 1922-2013 (Andrade, Rangel and Herrera, 2015). This will enable us to observe whether the temperatures recorded in 2020 were anomalous with respect to the climatology.

Hurricanes Eta and Iota

Tropical Storm Eta intensified explosively, reaching hurricane status at 09:00 UTC on 2 November in the central Caribbean Sea (Fig. 1), and just six hours later, the storm strengthened to a Category 2 hurricane. Eta reached Category 3 at 18:00 UTC 2 November and Category 4 three hours later. By this time, Eta had begun to decelerate and turn west-southwestward into the Colombia Basin. By 03:00 UTC on 3 November, the system was rapidly intensifying with maximum sustained winds of 240 km/h and with that intensity, it passed over the San Andres Archipelago. It then made landfall at 21:00 UTC south of Puerto Cabezas, Nicaragua, with winds of 225 km/h (National Hurricane Center [NHC], 2022a).

The seventh major hurricane of the record 2020 Atlantic hurricane season was Hurricane Iota (Fig. 1). This originated as a tropical wave that moved into the eastern Caribbean on 10 November. On 13 November, a tropical depression developed north of Colombia and it developed into Tropical Storm Iota six hours later. Conditions in the central Caribbean allowed Iota to rapidly strengthen into a hurricane on 15 November, becoming a Category 4 hurricane in the Colombia Basin and reaching its maximum intensity the following day with maximum sustained winds of 250 km/h. With this intensity it reached the San Andres Archipelago, devastating the island of Providencia.

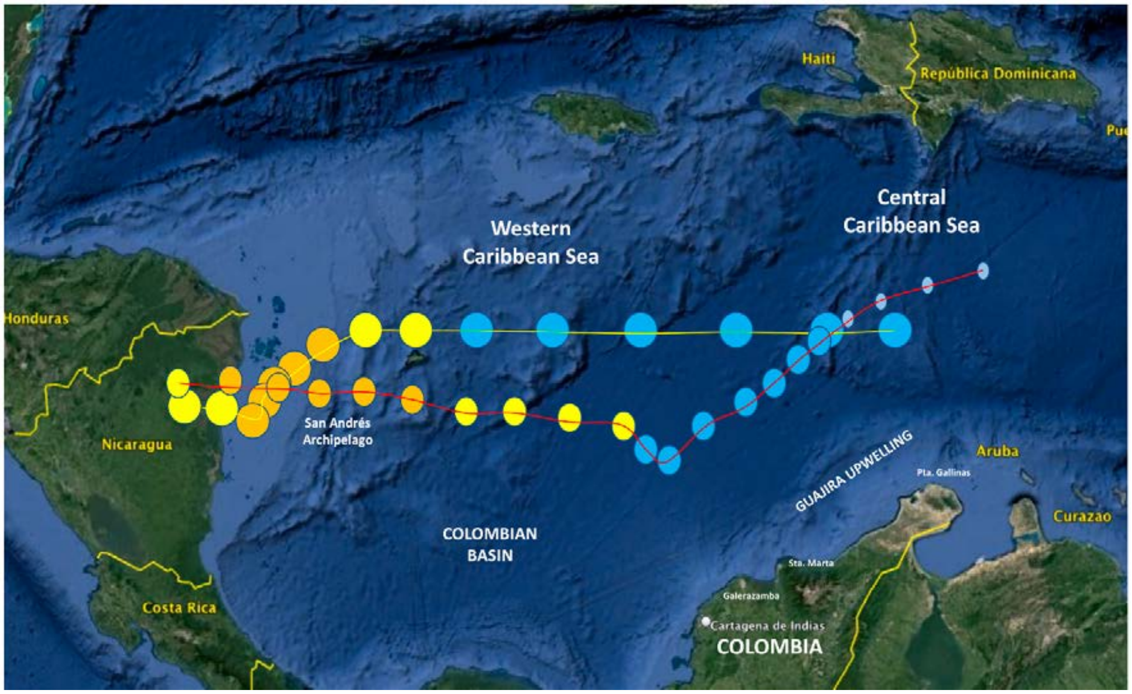

Figure 1. The study area with the paths of hurricanes Eta (yellow) and Iota (red) as they passed through the Colombian Basin. The circles indicate the position of the center of the anomaly every six hours. They are colored blue while they were tropical depressions, yellow for tropical storms and orange while they were hurricanes (NHC, 2022 a and b).

After reaching its maximum intensity, Iota moved to the same area where Hurricane Eta had passed two weeks earlier, leaving behind less warm waters, and as a result, it weakened and its maximum sustained winds decreased to values around 240 km/h. At that intensity, its eye passed close to the islands of Providencia and Santa Catalina. Iota's landfall location was approximately 25 km south of where Hurricane Eta had made landfall on 3 November (NHC, 2022b).

Methodology

The SSTs derived from radiance measurements collected by MODIS spectroradiometer instruments aboard NASA's Terra and Aqua satellites are estimates of the heat in the upper millimeter of the ocean (Tronin, 2017). The algorithm uses multiple atmospheric windowing techniques to estimate the atmospheric parameters needed to compensate for the absorption and scattering of radiated and reflected energy by the ocean.

The SSTs were determined based on MODIS-calibrated mid- and far-infrared (IR) radiances (MOD02 bands 20, 22, 23, 31 and 32), and using an algorithm that takes advantage of the differences in atmospheric transmissivity in the different IR bands to allow very accurate estimation of atmospheric effects. MODIS provides SSTs at spatial resolutions of 1 km (Level 2), and 4.6 km, 36 km and 1° (Level 3) over the oceans of the world (Kilpatrick *et al*., 2015). Among the corrections applied, a land mask is used to mark non-water pixels, while an ice mask limits polar sea coverage. A sequence of spatial and temporal homogeneity tests is applied to validate the quality of the cloud-free observations. Because sun glint is a significant source of error in the IR bands, the cloud mask is critical to identify the glinting pixels, as are the ancillary sea surface wind data used to estimate the radiance of the glinting area (Castillo and Lima, 2010).

The temporal coverage of the present study included images from ten days in the 2020 hurricane season (Table 1). The images were downloaded from the database as raster files and processed in ARCMap®, to obtain sufficient contrast to highlight the area with SST > 26 °C.

Table 1. List of dates and file name of MODIS-Aqua satellite images available for the 2020 hurricane season.

	Month (date)	File name of the images
1	June (2020-06-01)	MYD28W_2020-06-01_rgb_3600x1800.FLOAT
2	June (2020-06-17)	MYD28W_2020-06-17_rgb_3600x1800.FLOAT
3	July (2020-07-19)	MYD28W_2020-07-19_rgb_3600x1800.FLOAT
4	August (2020-08-20)	MYD28W_2020-08-20_rgb_3600x1800.FLOAT
5	September (2020-09-05)	MYD28W_2020-09-05_rgb_3600x1800.FLOAT
6	September (2020-09-21)	MYD28W_2020-09-21_rgb_3600x1800.FLOAT
7	October (2020-10-07)	MYD28W_2020-10-07_rgb_3600x1800.FLOAT
8	October (2020-10-31)	MYD28W_2020-10-31_rgb_3600x1800.FLOAT
9	November (2020-11-24)	MYD28W_2020-11-24_rgb_3600x1800.FLOAT
10	December (2020-12-18)	MYD28W_2020-12-18_rgb_3600x1800.FLOAT

Using the MODIS images, SST values were estimated for the Colombian Basin during the 2020 hurricane season. In particular, the SST data obtained in the area of the La Guajira upwelling system were compared with the description of SST by sectors of the Colombian Caribbean coast presented in Bernal *et al*. (2006) and the statistical calculation of SST presented in the Oceanographic Atlas of the Colombian Caribbean Sea (Andrade *et al*. 2015). The former was done using long-term satellite databases (COADS database from 1982 to 2002) and the latter with *in situ* oceanographic data from several decades.

Results

Description of the thermal images

The sequence of images obtained made it possible to observe the SST field of the Colombian Caribbean from June to December 2020. The images obtained show the SST on days when there was minimal cloud cover. The image in Figure 2a shows that, on 1 June 2020, the Colombian Caribbean was covered by surface waters warmer than 26 ºC, with the exception of the waters associated with the La Guajira upwelling. In this area, 23 ºC water was upwelling between Punta Gallinas and Santa Marta, and the upwelling reached as far as Galerazamba. Two weeks later, a filament of the upwelling moved water of about 25 ºC around 300 km to the center of the Basin as shown by the 26 ºC isotherm (Fig. 2b).

The 26 ºC isotherm defining the outer edge of the upwelled surface water near La Guajira is visible in the June images (Fig. 2a and b), with patches marking the path of a filament exiting the upwelling area to the west-northwest, as an eddy and the pool of cold water off La Guajira remaining close to the peninsula area until mid-July (Fig. 3a).

During the months of August (Fig. 3b), September (Fig. 3c and d) and October (Fig. 3e and f), the water in the entire western Caribbean was found to be between 27 ºC and 31 ºC and the upwelling area disappeared. Despite several hurricanes passing through this sector, the SSTs remained in this range, with particular warming in the month of October, when patches of surface water of around 31 ºC were observed, especially along the coast of Colombia south of 12 ºN.

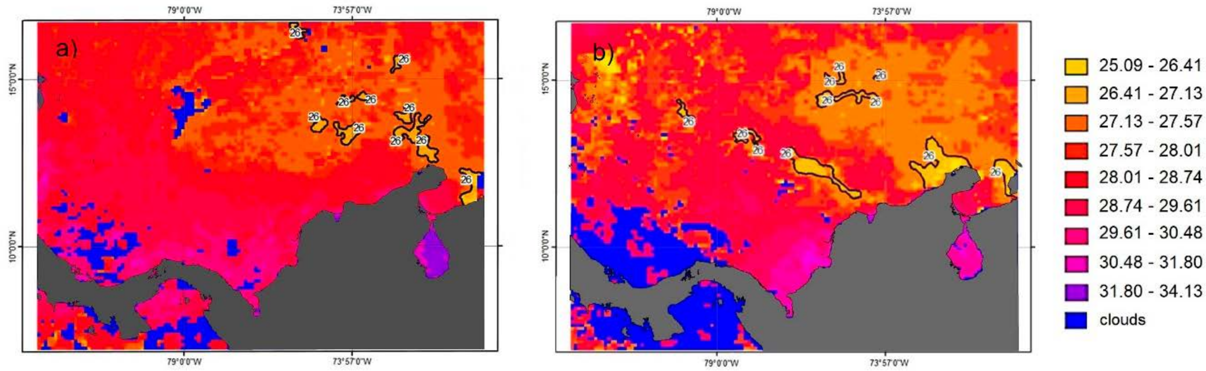

Figure 2. SSTs in the Colombian Caribbean: a) 01 Jun 2020 when the hurricane season started, and b) 17 Jun 2020.

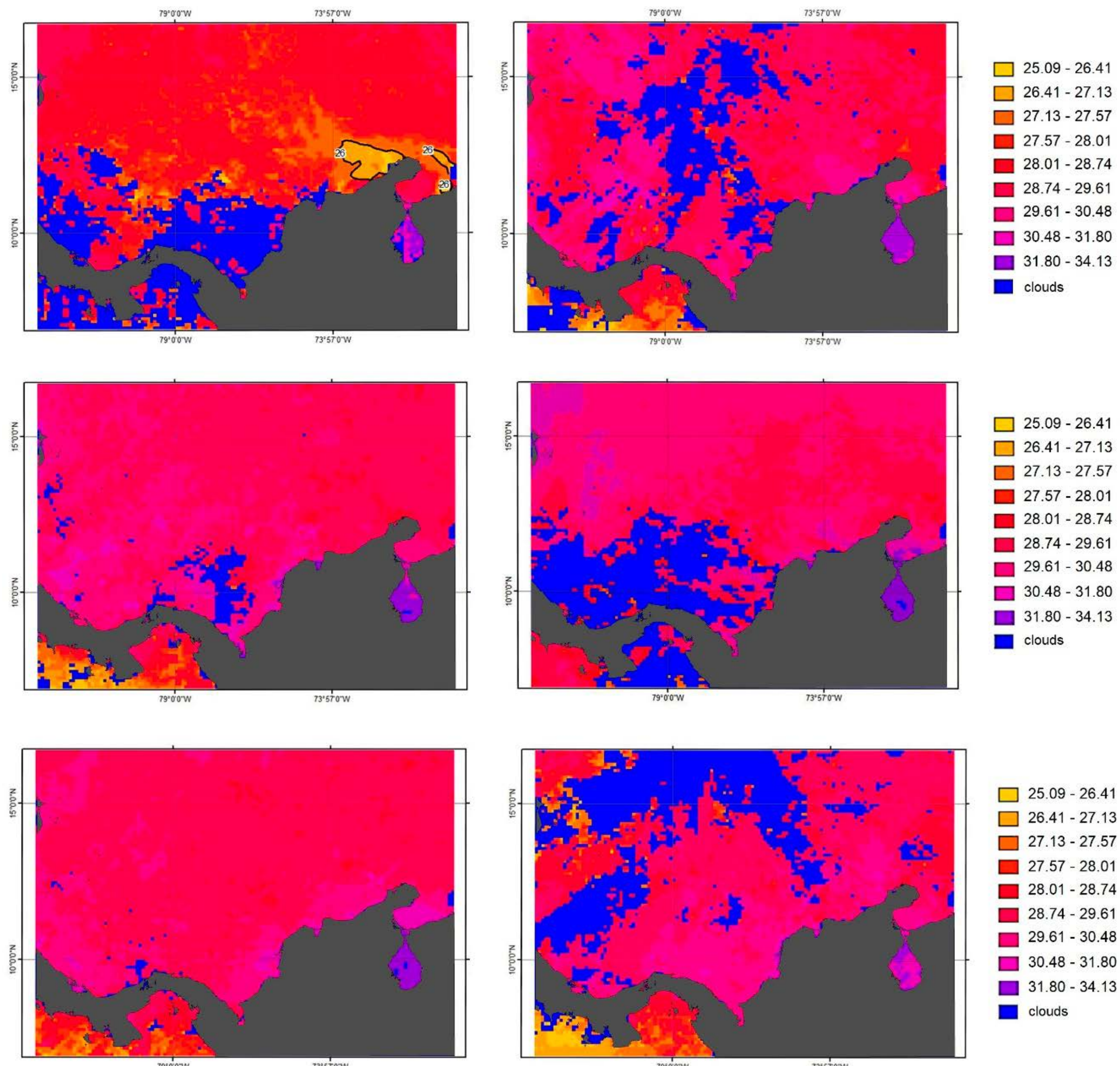

Figure 3. SSTs in the Colombian Caribbean: a) 19 Jul 2020, b) 20 Aug 2020, c) 05 Sep 2020, d) 21 Sep 2020, e) 07 Oct 2020 and f) 31 Oct 2020.

During November 2020 (Fig. 4a) the Colombian Caribbean was a very homogeneous pool of water, with SSTs greater than 28 ºC, and the upwelling area (the 26 ºC isotherm) does not appear at the surface until late in the month, when the system cools ostensibly. Temperatures in the December images are lower than in the previous month and the upwelling system is clearly seen in the image with a tongue extending from the Guajira Peninsula to the center of the basin (Fig. 4b).

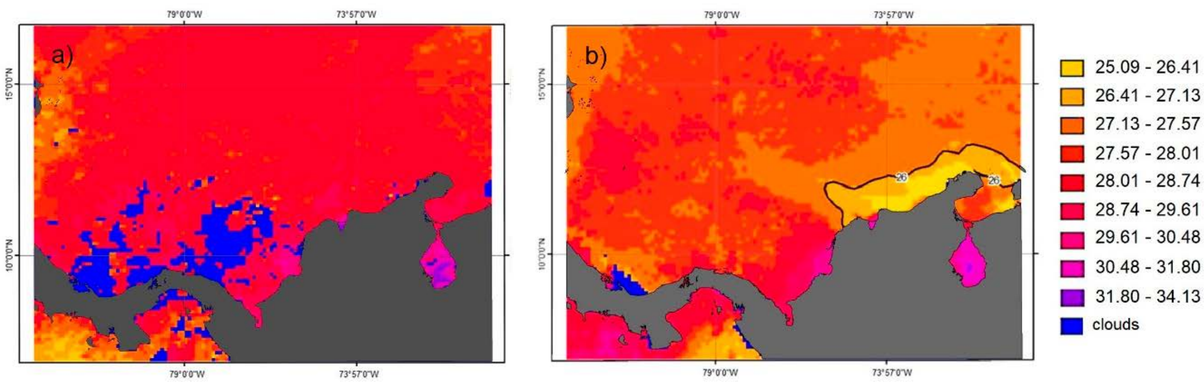

Figure 4. SSTs in the Colombian Caribbean: a) 24 Nov 2020 and b) 18 Dec 2020.

SST analysis in the La Guajira upwelling

Figure 5a shows the mean annual cycle of the SST between 1982 and 2002 for the coast of Colombia described in Bernal *et al*. (2006). The red line corresponds to the end of the La Guajira peninsula and the red dots represent the SST found in the images from June to December 2020 in this work. The standard deviation of this series can be found in Figure 5b. The descriptive statistics of the SST series showed that, in the La Guajira area, the mean temperature is 27.05 ºC, the minimum SST was 24.5 ºC, and the maximum temperature has reached 29.54 ºC on occasions (Bernal *et al*., 2006).

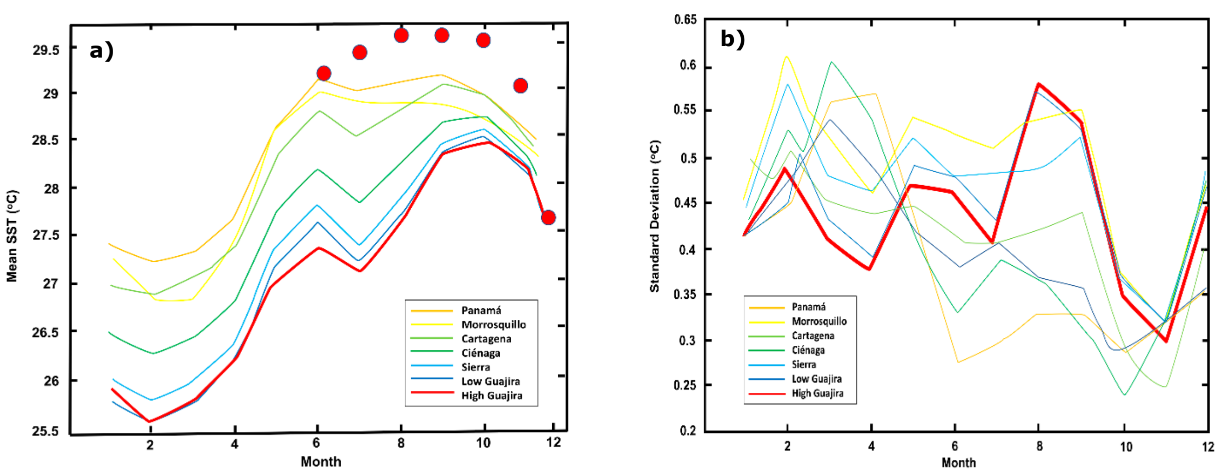

Figure 5. SST (a) and standard deviation in SST figures (b) presented in Bernal *et al*., 2006 (continuous lines) and found in this work during the second half of 2020 (red dots).

Figure 5a shows that the SST from June to December 2020 was anomalous from June (about 2 ºC higher than expected) and kept rising until September, when it was about one degree above the mean. For the month of November, it was even above the expected standard deviation for that month (Fig. 5b), and it only reached normal levels in December. A particularity found in 2020 was the fact that there was no cooling signal corresponding to the passage of the July dry season known as the Veranillo (Pujos and Le Tareau, 1988; Mesa *et al*., 1997); on the contrary, SST continued to increase, and it remained high throughout the semester until December, when it returned to normal values according to the mean values described in Andrade, Rangel and Herrera (2012).

It is important to note that the SST values of the second half of 2020 were around 29.5 ºC, even higher than values found at La Guajira peninsula during La Niña events, in which maximum values of 29 ºC had been recorded in those years during the period studied by Bernal *et al*. (2006) (Fig. 6).

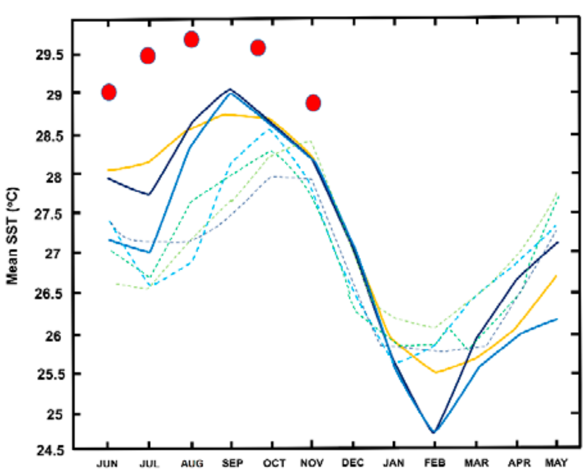

Figure 6. SSTs during El Niño years (dashed lines) and La Niña years (solid lines) presented in Bernal *et al*. (2006). The red circles indicate SSTs for the corresponding months in 2020.

The comparison between the SST of the upwelling area and the wind intensity based on the 20 years analyzed in Bernal *et al*. (2006), shows that there is a direct relationship between the decrease in the northern trade winds and the increase of the temperature for La Guajira (Fig. 7a); and similarly, there is a direct relationship between the strengthening of the Chocó jet and the increase in the SST of La Guajira (Fig. 7b). In both circumstances, this would imply that the unprecedented SST, higher than 29 ºC, detected between June and December 2020 could be related to the significant absence of the zonal (east to west) component of the Northern Trade Winds and/or the significant increase of the zonal (west to east) component of the Chocó jet.

a)

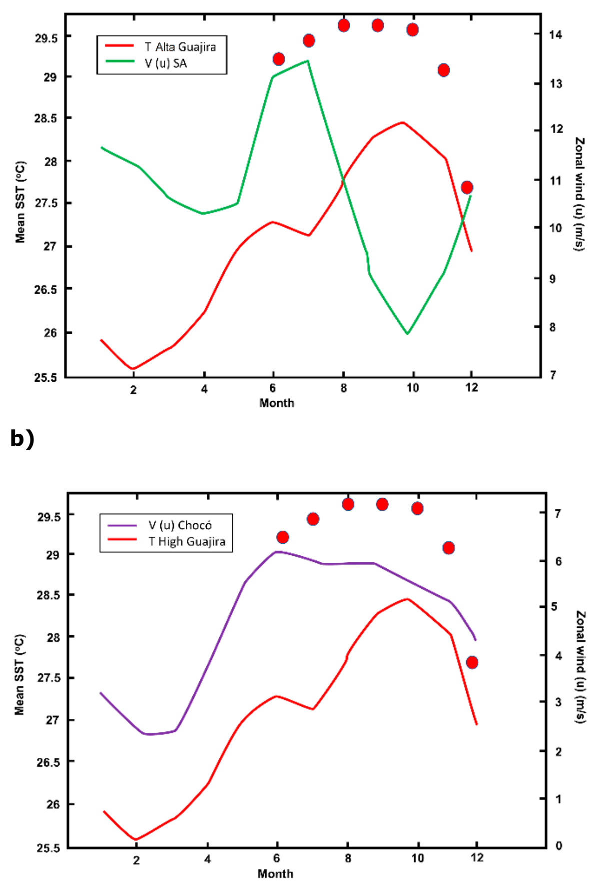

Figure 7. The mean SST in the upwelling area compared with (a) the zonal component of the Northern Trade Winds, and (b) the zonal component of the Chocó jet. Modified from Bernal *et al*. (2006). The red circles indicate SSTs for the corresponding months in 2020.

Discussion

The comparison between the geographic statistics calculated for the Colombian Caribbean in the upwelling area of La Guajira (Bernal *et al*., 2006) and the data from the images of the 2020 hurricane season, showed that no SST values similar to those recorded in the area during July-December 2020 are found historically, neither in the monthly means, nor in the seasonal mean of the rainy season that corresponds to the hurricane season, even when adding the highest values of the standard deviation calculated for these areas.

When comparing spatially with the findings of Andrade, Rangel and Herrera (2015), a similar behavior can be observed (Fig. 8): The 1922-2013 multiannual monthly mean shows that it is only common to find values of 28 ºC beyond latitude 14 oN and that, exceptionally, maximum standard deviation values would allow SST values of 29.2 ºC to be normal north of 14 ºN, but these are abnormal within the upwelling zone.

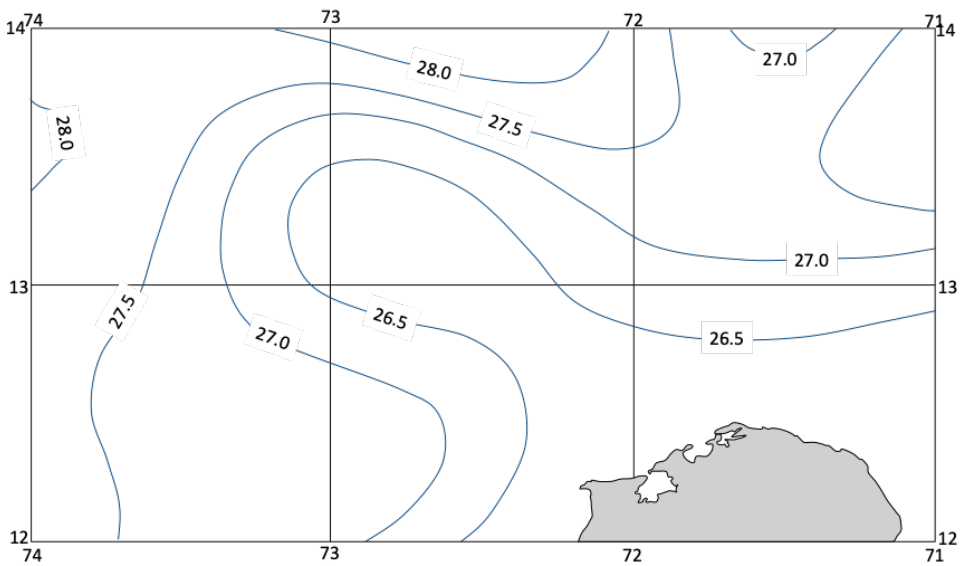

Figure 8. Multi-annual monthly mean SSTs (1922-2013) in the La Guajira upwelling area. Taken from: Oceanographic Atlas of Colombia (Andrade, Rangel and Herrera, 2015).

The same comparison was performed on the seasonal mean for the rainy season (Fig. 9). This showed that, although the SST values are not typical of an upwelling area and values similar to those measured in 2020 have been detected only north of latitude 15 ºC; there is no recorded history of the temperatures shown in the 2020 hurricane season images.

The abnormally high SST values, above 29 ºC and extending all over the Colombian Caribbean during a period as long as the one presented in the thermal images of the 2020 hurricane season, are exceptional; but at the same time they mean that the probability of occurrence has a new reference point that allows the development of hurricanes such as Eta and Iota, which reached categories 4 and 5 in their passage through the San Andrés Archipelago and Central America. This condition also shows that the upwelling area in La Guajira can disappear completely on the surface during these periods.

Another aspect to bear in mind is the effect of El Niño Southern Oscillation (ENSO) events in their warm and cold phases. By the time of the 2020 assessment, the ENSO index was strengthening towards a La Niña event during July (-0.6) to November (-1.3), when it reached its minimum (Fig. 10), suggesting that there could be a wind push towards the east correlated with the presence of the Chocó jet that would have slowed down the surface circulation, allowing the abnormal increase in SST.

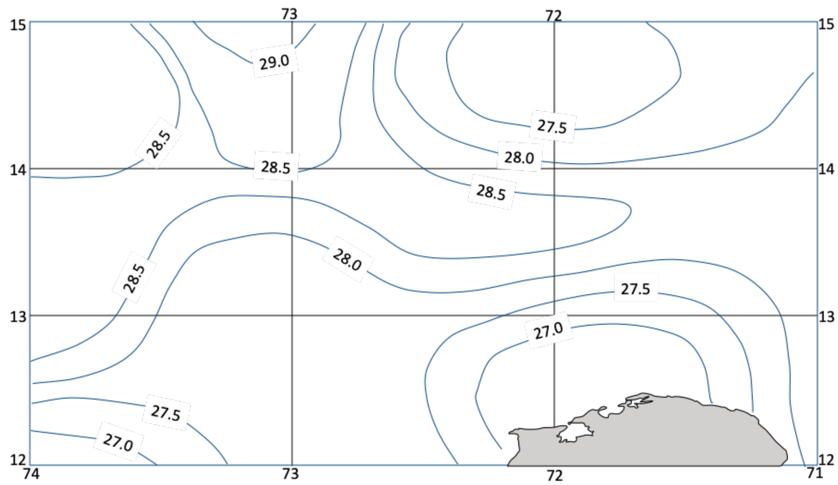

Figure 9. Mean SST in the La Guajira upwelling area during the rainy season. Taken from: Oceanographic Atlas of Colombia (Andrade *et al*., 2015).

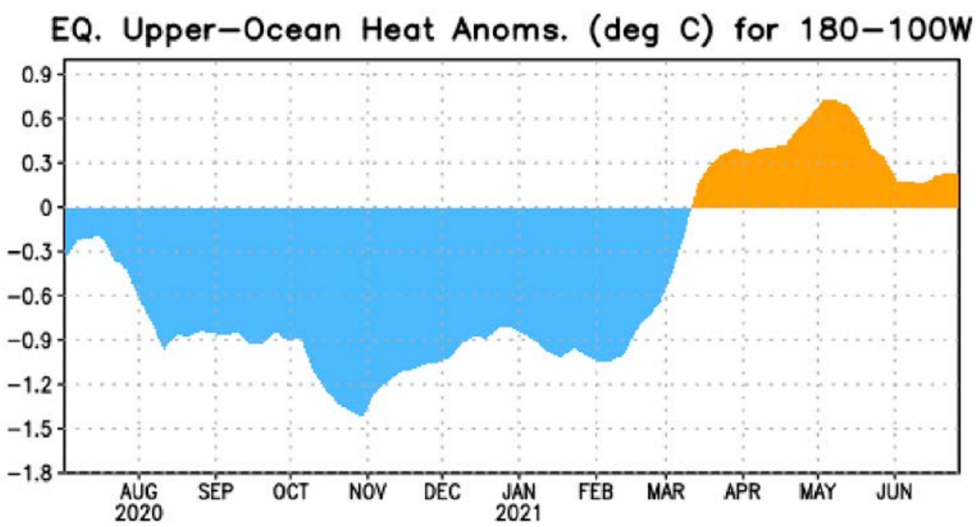

Figure 10. Temperature anomaly in El Niño region 3, showing the presence of La Niña, which reached its maximum intensity during November 2020 (National Oceanic and Atmospheric Administration [NOAA], 2022).

The upwelling regime appears to have normalized rapidly in December 2020 with the arrival of northerly winds, making this anomalous event, which accompanied the passage of two major hurricanes, a very sharp and conspicuous anomaly.

Conclusions

The SST values present during the 2020 hurricane season in the upwelling area (Alta Guajira), were abnormally high when compared to the mean values analyzed with 20-year data from the COADS database in Bernal *et al*. (2006). These values were even higher than those found in the "warm water pool" that is normal in the southwestern of the Colombian basin.

These SST values, higher than 29 ºC in the entire upwelling area and the Colombian Caribbean in general, are exceptional and constitute a new standard to be examined, since these temperatures occurred during the development of hurricanes Eta and Iota, which reached categories

4 and 5 in their passage through the San Andres archipelago and Central America.

The anomalous increase in SST in the Colombian Caribbean during 2020 corresponded with a peak in the negative temperature anomaly in El Niño 3 region, which indicates the occurrence of a La Niña event, a time when the Chocó jet tends to be abnormally more intense in its eastward flow, counteracting the trade winds and the surface circulation. These circumstances could explain the abnormal surface warming.

A continuous monitoring of the SST of the La Guajira coastal upwelling area in Colombia, may improve predictions for storm events entering the Caribbean and passing through this area towards the archipelago of San Andres and Providencia, in particular.

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