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Possibility of Predicting Category 5 Hurricanes in the Eastern Pacific Ocean

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Abstract: Every year, destructive Category 5 hurricanes affect wildlife, causing great ecological destruction and economic losses. The ability to forecast Category 5 hurricanes is essential to minimize people's risks and vulnerabilities. We present an original methodology utilizing Machine Learning to develop models that give insights into the complex relationship between the atmosphere-ocean system and Category 5 hurricanes in the eastern Pacific Ocean since 1950 years. The model apply Machine Learning techniques to observed records of Category 5 hurricanes in the eastern Pacific Ocean, climatic and environmental factors. The aim is to identify climatic variations and oceanographic conditions that induce high and low cycles of activity Category 5 hurricanes in the eastern Pacific Ocean. Machine Learning models suggest that a new phase of high activity Category 5 hurricanes will start in 2025 and run until 2030 — created by multi-annual climatic variations of the atmosphere-ocean coupled system. The new results can develop policies to transition from a near-term reactive response system to a longer-term strategy for an effective disaster prevention system. They can also be used to modernize the current early warning systems of Hurricanes now existing in Mexico.

Key words: Eastern Pacific Ocean, Category 5 hurricanes.

1. Introduction

At present, it is not yet known with certainty the frequency in which hurricanes may occur, since this may be due to many factors; among others, the fluctuations in the temperature of the oceans, the speed of the winds, etc. On average, 80 hurricanes occur throughout the world every year, distributed in several regions, for example, in the Eastern Pacific, an average of 15 hurricanes per year happen (including all categories), which represents 18.7% of the total hurricanes that take place annually. The annual number of hurricanes depends on fluctuations in the ocean-atmosphere relationship. Phenomena such as El Niño, influence the occurrence and trajectory of tropical storms, increasing their appearance by almost 28%.

Events such as C5H (category-5 hurricanes) are considered as a random phenomena associated with complex physical configurations, the frequency in which they appear is still poorly understood, it is generally related to several variables, such as cycles of solar activity, climatic variations, processes related to human activities and others.

A large number of phenomena that occur in nature have a behavior that can be described by means of periodic functions. The occurrence of C5H in the Eastern Pacific also presents this behavior. Analyzing the series in time in which hurricanes occur, characteristic oscillatory periods have been observed that describe certain trends, although these periods are linked to physical processes that are not yet clearly identified, correlations have been found of some periodicities present in hurricanes with other time series, such as the anomaly in the sea surface temperature (SST), the El Niño phenomenon and others.

Following a procedure similar to that we did in a previous work [1] for the Atlantic Ocean, in the present study we have perform a spectral analysis of

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various time series by means of the wavelet transform, then we analyze with the Machine Learning method [2] the behavior of the periodicities that have more energy in the Eastern Pacific. The aim is to characterize a temporal region where is possible that occur the formation of C5H in the Eastern Pacific, namely, it is a question of finding a time interval where the formation of this kind of hurricanes is favorable. We emphasize, that this work is not focused on determining how many hurricanes may occur, or precisely determining the days on which they will happen. What we are trying to do is determine time intervals that define a probable region for the occurrence of the following C5H based on the information obtained by the Machine Learning method.

The method we have used to analyze the occurrences of C5H in the Eastern Pacific is based on the quasi-oscillatory behavior of the temporal distribution of high-category hurricanes, relating their occurrences to the oscillatory period of various time series present in the Eastern Pacific, in order to obtain characteristic oscillation periods that describe the phenomenon.

We use for this purpose The National Oceanic Atmospheric Administration (NOAA) database [1], which contains all the hurricanes formed in the Eastern Pacific since 1950 to present. Several hurricanes never made landfall, but developed and dissipated in the open sea, so that, several hurricanes that occurred in the late nineteenth and early twentieth centuries are not present in this database [3]. However, using satellite images from the NHC (National Hurricane Center) of USA since 1966, the estimation of parameters and trajectories from hurricanes became more accurate. The NOAA database has 94 category-4 hurricanes and 18 category-5 for Eastern Pacific Ocean, the latter are the most interesting due to their high destructive effects and because they are the phenomenon with the most energy present in the atmosphere, whose occurrence is assumed to be random in the nature. In the absence of a physical theory that allows us to predict this random phenomenon, we develop in this work a mathematical tool that allows us to approach the problem.

Among the many parameters that affect the formation of hurricanes in the Pacific, one of the most significant is undoubtedly the sea surface temperature (SST) in the Eastern Pacific[2]. The SST anomalies are very important in the formation of hurricanes, since they represent the high temperatures on the sea surface and in addition, they are also a key factor in determining the direction of storms and in maintaining their growth and existence. Furthermore, several studies have found that there is a correlation between the number of SST and the occurrence of hurricanes in the Atlantic [4]. We think that this also happens for the Eastern Pacific.

Fig. 1 shows the monthly values of time series of the SST anomaly in the Pacific Ocean for the East Pacific/North Pacific región (EP), describing the period from 1950 to 2020. The surface temperature data were obtained from the ICOADS (International Comprehensive Ocean Atmosphere Data Set)[3] of the NOAA available at the prevouosly mentioned website.

The middle panel of Fig. 1 shows the wavelet power spectrum of the SST series calculated with the wavelet analysis [5, 6]. In the global spectrum (left part in Fig. 1), the dominant periodicities of these series are observed.

It should be mentioned that in a coherence analysis of Hurricanes vs. SST [7] we found the periodicities of 1, 3, 11 and 22 years but for the Atlantic. On the other hand, if only the hurricanes (either category 4 or 5) are considered in the wavelet analysis, very close periodicities were obtained [8] using only the temporal distribution of the hurricanes series, independently of intensity and other characteristic of individual events. By means of hurricanes data from the National

[1] https://coast.noaa.gov/hurricanes.

[2] http://www.cdc.noaa.gov/coads/.

[3] https://icoads.noaa.gov.

Weather Service, the authors transformed them into a series of pulses, with the technique of PWM (pulse width modulation), where n = number of hurricanes, as n = 1 meaning the day with category-5 hurricanes and n = 0 meaning the day without hurricane register. Under this approach, periodicities of 1, 2, 10, 14 and 24 years were found, and some of them were also concordant with those from the coherence analysis of SST vs. hurricanes [7].

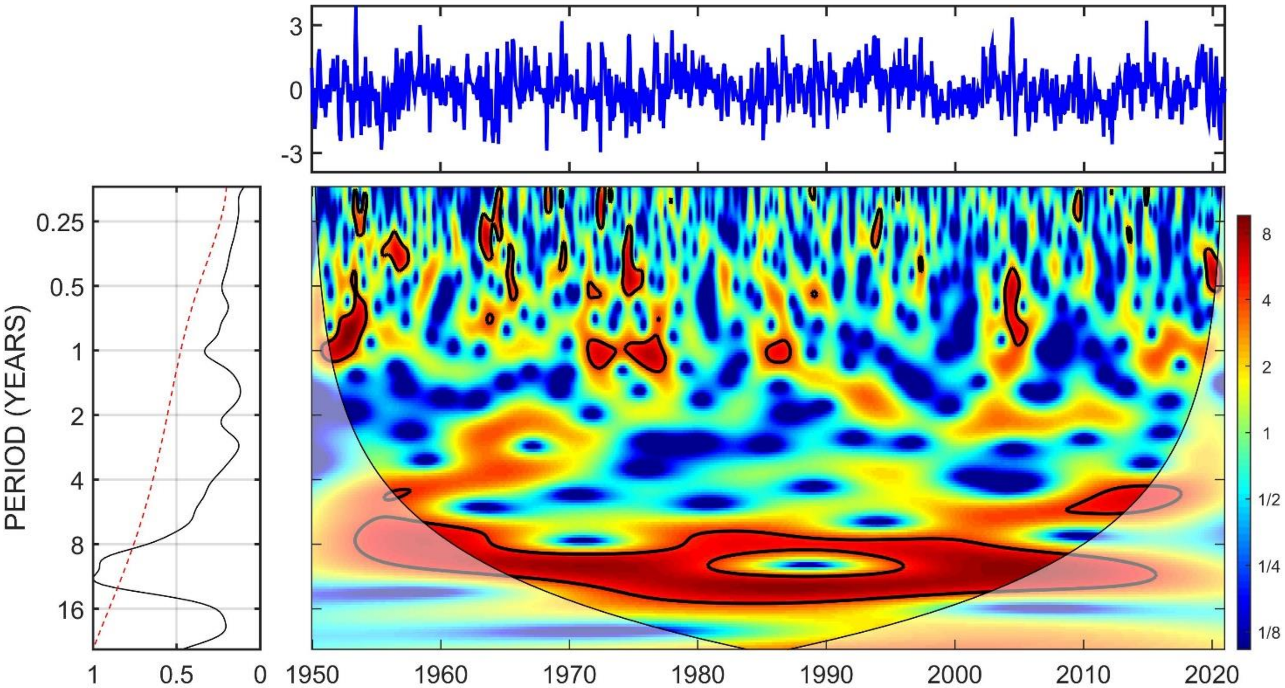


Fig. 1 Spectral Analysis: the Upper panel is the anomaly in the sea surface temperature (SST) in the Pacific Ocean for EP/NP region, the middle panel is the wavelet spectrum and the left panel is the global energy spectrum.

In the previously mentioned work [8, 9], the occurrence of these type of hurricanes in the past was always found close to the maximum value (peak) or minimum value (valley) in all the studied periodicities. With these features and extrapolating forward in time in the periodic behavior, the authors computed time intervals where these features are met. In this way, it can be assumed when a category-5 hurricane may occur in the future. However, in that approach, the study of the behavior of the periodicities in the occurrence events was limited to those empirical findings, that is, the obtained information was limited to determine if the event occurred within the peak or valley phases of a certain periodicity.

In the present study, we leave the empirical aspect, but we continue to use Wavelet Analysis as the fundamental assumptions, emphasizing the importance of the behavior of periodicities to describe the occurrence of hurricanes. We have used such results obteined with the Wavelet Analysis and the time series to apply next the Machine Learning method.

2. Data and Analysis

In this section we present the data obtained from the Wavelet and Cross-Wavelet analysis for the main phenomena that occur in the Eastern Pacific Ocean, namely, the time series of temperature oscillations and the historical data of category 5 hurricanes.

The time series that we have used are the following:

1) East Pacific/North Pacific Oscillation (EP / NP).
2) Pacific Decadal Oscillation (PDO).
3) Niño 1+2.

4) Niño 3.4.
5) Niño 4.

All the previous series describe a time period from January 1950 to December 2020. We have used these time series because we consider that they are the most influential among all the others that have been elaborated from 1950 to the present.

The ENSO (El Niño South Oscilation), refers to the natural fluctuation of sea surface temperatures and the atmospheric pressure between the East and West of the Tropical Pacific Ocean. The ENSO refers then, to the resulting coupling between what is happening with the temperatures of the sea surface and the behavior of the atmosphere. These fluctuations can generate three scenarios: hot, cold and neutral. The hot phase is known as El Niño and the cold phase as La Niña.

When we talk about El Niño, we refer to a hot phase in the waters towards the Central and Eastern Pacific Ocean Tropical, between 5° north and south latitude. This warming in the ocean could reach between one and three degrees above the average value of temperatures in that ocean area. The warming in surface water of the ocean is kept by the heating between the surface of the ocean and 300 meters deep.

When we talk about La Niña, we refer to a cooling on the ocean surface Tropical Pacific (in the same area where El Niño occurs). This decrease in temperature of the sea surface is induced by a cooling in the deep waters of the ocean.

Temperature variations on the sea surface due to the occurrence of El Niño or La Niña phenomenon produce changes in the circulation of the ocean and atmosphere, causing disturbances in the patterns climatic at a planetary level, which gives rise to extreme hydrometeorological events, such as droughts and floods in different areas of the planet. These events have an average duration of 10 to 18 months and repeats between every 2 to 7 years.

For monitoring El Niño and La Niña, the Equatorial Pacific Ocean has been splitin in four regions, namely: Niño 1+2, Niño 3, Niño 3.4 and Niño 4. Table 1 shows each of the Niño regions, with the latitude and longitude details that define them and Fig. 2 shows the geographical representation of the regions mentioned above.

Table 1 Niño Regions.

Regions	Longitude	Latitude
Niño 1+2	90°W and 80°W	0° y 10° S
Niño 3	150°W and 90°W	5°N y 5°S
Niño 3.4	170°W and 120°W	5°N y 5°S
Niño 4	160°E and 150°W	5°N y 5°S

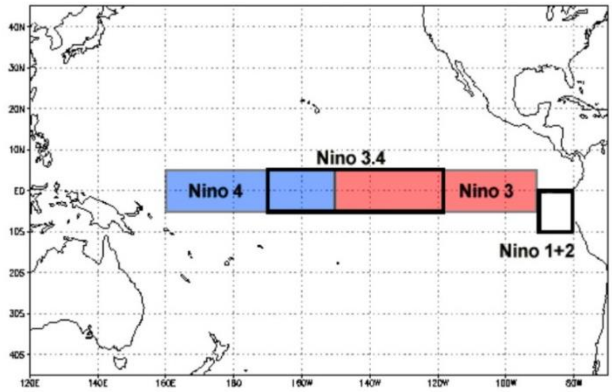


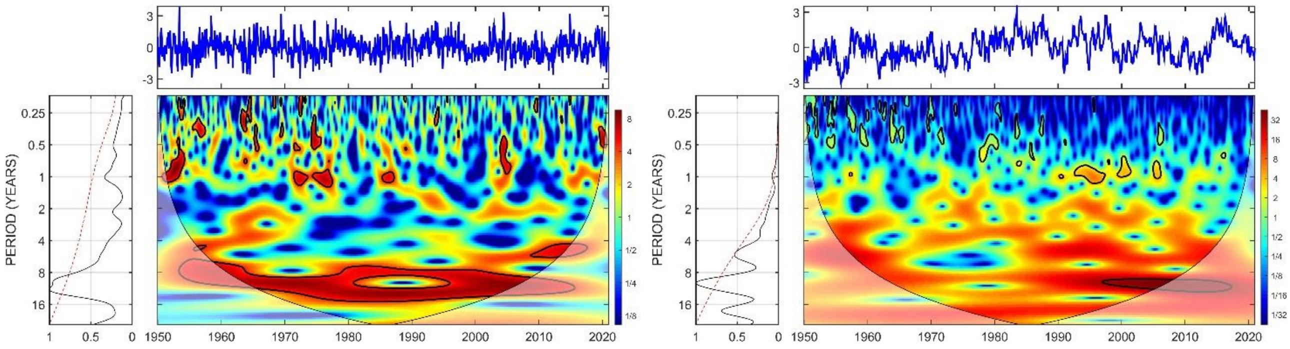
Fig. 2 Niño Regions (image taken from NOAA).

Regarding the Niño 3.4 region, the NOAA has defined an index to monitor and define when the ENSO occurs or ends. This is El Niño Oceanic Index (ONI), which is calculated as the three-month average of the anomalies of surface temperature of the sea for El Niño region 3.4.

2.1 Wavelet and Cross-Wavelet Analysis Results

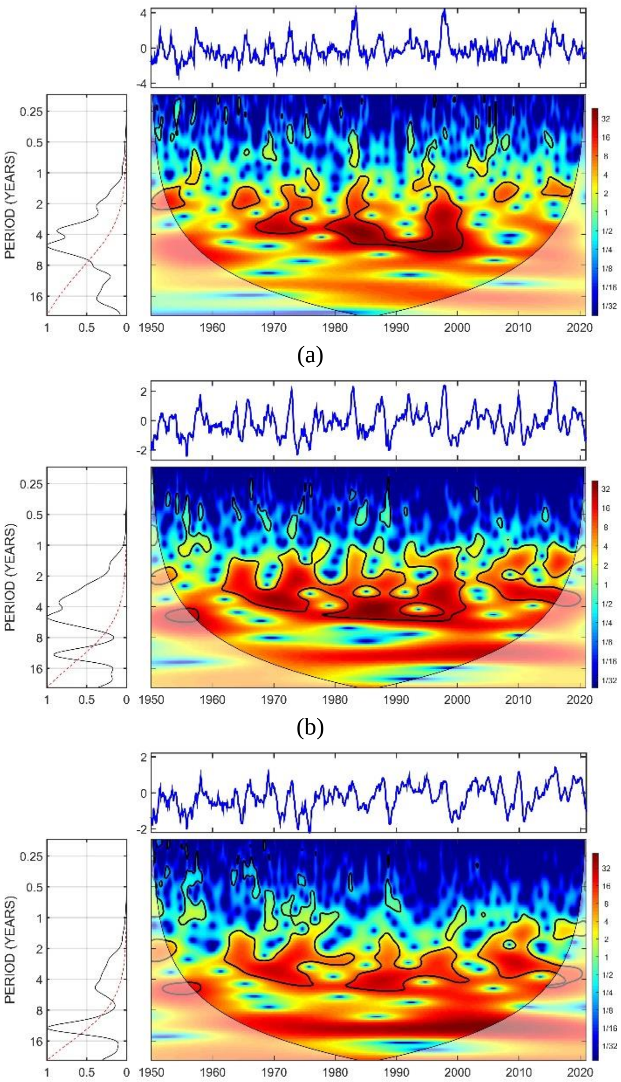
In this section we present the results obtained from the Wavelet and Cross-Wavelet analysis for the main phenomena that occur in the Eastern Pacific Ocean, namely, the time series of temperature oscillations and the historical data of category 5 hurricanes.

Also, we present the figures that were obtained from the Wavelet analysis of the time series mentioned above. In these figures, the top panel shows the time series being analyzed, the central panel denotes the wavelet spectrum, and the left panel is the global energy spectrum.



(a) (b)

Fig. 3 Wavelet analysis for: (a) East Pacific/North Pacific oscillation (EP/NP) and (b) Pacific Decadal Oscillation (PDO).



(c)

Fig. 4 Wavelet analysis for: (a) Niño 1+2, (b) Niño 3.4 and (c) Niño 4.

Fig. 5 shows the wavelet spectral analysis of category 5 Hurricanes. The top panel indicates the occurrence dates of the 18 category 5 Hurricanes, the central panel denotes the wavelet spectrum, and the delimited left panel is the global energy spectrum.

For each one of the series we have determined the predominate, and the corresponding years in which each period occurs. For all the time series the global spectm (the confidence leve) are lower thean 95% (0.3, 0.6, 1.1, 1.5, 2.7, 7.8 y 19.6 years). Only the 4.1 year shows a confidence level obove 95%, where the spectral power density (SPD) is particularly intense in the period 1995-2020. It can also be observedt that there is a scarce number of huracanes category 5 between 1950 and 1990 and that makes very dificult to pronosticate the next hurricnes category 5 in the Pacific Ocean.

In order to find patterns that indicate the occurrence of hurricanes of category 5 it is necessary to analyze the hurricanes with their climatic and oceanographic variables that provide us information about the evolution of the C5H. For this reason we have proceeded the cross-wavelet between the C5H and the EP/NP, to determine such patterns, that indicate the occurrence of hurricanes of category 5 it is necessary to analyze the hurricanes with their climatic and oceanographic variables that provide us information about the covariations that ultimately will give us with information about the patterns when the C5H do occur.

Fig. 6 shows that also for the cross-global wavelet most of periodicities are lower than 95%: 0.3, 0.6, 0.8, 1.1, 2.3, 5.7, 7.8, and 11.7 years. In the central panel it can be observed that the spectral power for these periodicities is intermittent, which would indicate that these periodicities are related to the oceonography and climatic particular conditions of the C5H ocurrene, that entails than are not these pattern that explain the high and low season of the C5H. Is just for this reason that we have analyzed the cross-wavelest btween the C5H and the EP/NP in order to find the covariances that provide us information of the patterns when the C5H ocurr in an intermittent way. For this reason these periodicities cannot be used as patterns to predict C5H for the near close C5H.

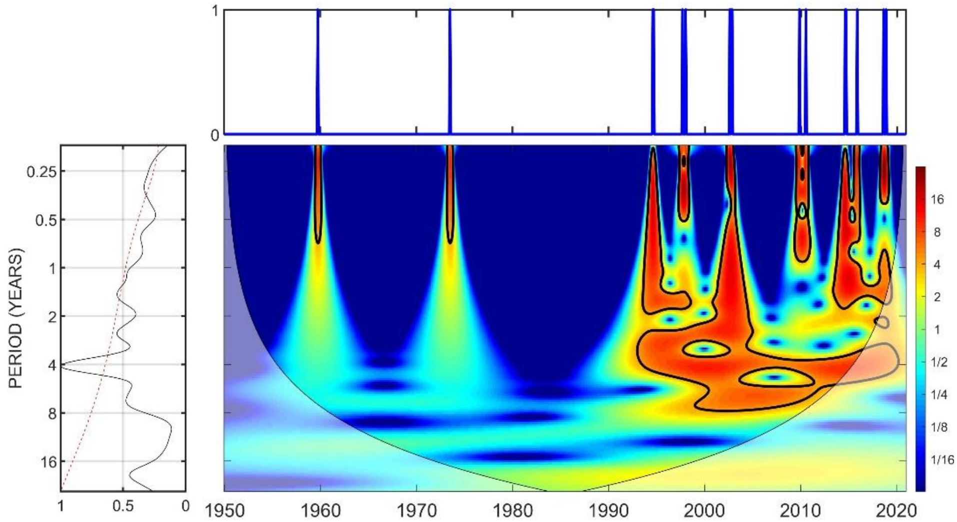


Fig. 5 Wavelet analysis for category 5 hurricanes.

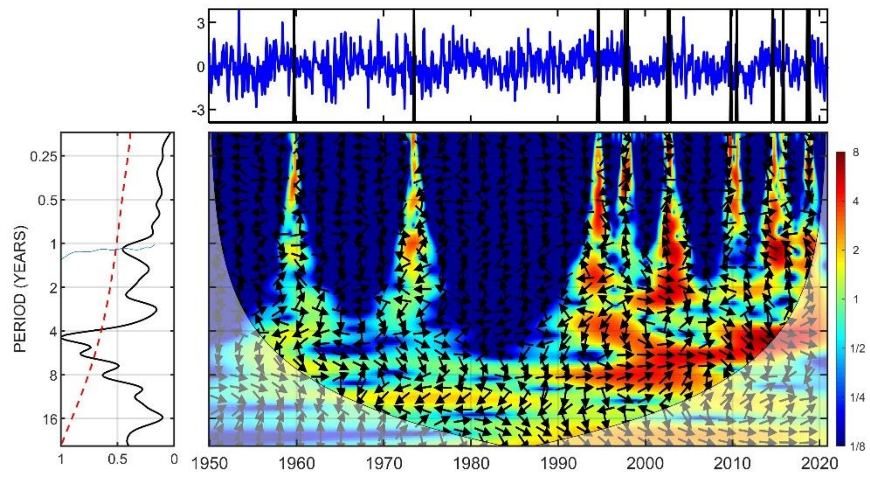


Fig. 6 Cross-wavelet analysis for Category 5 hurricanes and EP/NP.

Again the only periodicity above 95% is that of 4.1 year and again it can be observed that it is very intense between 1950 and 1990. In other years the spectral power is rather weak due to the scarse number of C5H.

From the fact that there exist a very intense covariance between C5H and EP/NP just in the periodicity of 4.4 year, this could be indicative that this periodicity could be one of the patterns that could be used to explain the ocurrence of C5H and therfore, may be used to predict the next high temporade of C5H.

That is why we have analyzed the cross wavelet between C5H and EP/NP to find the covariations that provide information on the patterns of when C5H and in order to find the patterns that indicate the occurrence of category 5 hurricanes, it is necessary to analyze the C5H with climatic and oceanographic variables that provide information on the development of the C5H. That is why we have analyzed the cross wavelet between C5H and EP/NP to find the covariations that provide information on the patterns when C5H are intermittent, so this would indicate that these periodicities are related to the particular climatic and oceanographic conditions of occurrence of these C5H, so they would not be the patterns that explain the high and low seasons of the C5H. In addition, these periodicities cannot be used to forecast the occurrence of C5H for the following years.

The only periodicity greater than 95% is again the periodicity of 4.4 years and it can be observed that the spectral power is very intense between 1990 and 2020. Between 1950 and 1990 the spectral power is weak due to the low number of C5H. But the fact that there is a very intense covariance between the C5H and the EP/NP in the periodicity of 4.4 years could be an indication that this periodicity could be one of the patterns that can explain the occurrence of the C5H and could be used. to forecast the next C5H peak season.

Fig. 7 shows the results of the covariance between C5H and PDO. The global wavelet cross wavelet shows that the periodicities less than 95% of the confidence level are: 1, 1.8, 2.5, 5.8, 8.5, 10.4, and 18.5 years. The multi-annual periodicities are intermittent, while the decadal periodicities (that is, 10.4 and 18.5 years), although their spectral power is intense and the phase shows a linear relationship (arrows from left to right), these periodicities do not explain the occurrence of C5H. Again, the periodicity of 4.4 years has more than 95% of the confidence level, and its spectral power is very intense. Furthermore, the phases show a linear relationship.

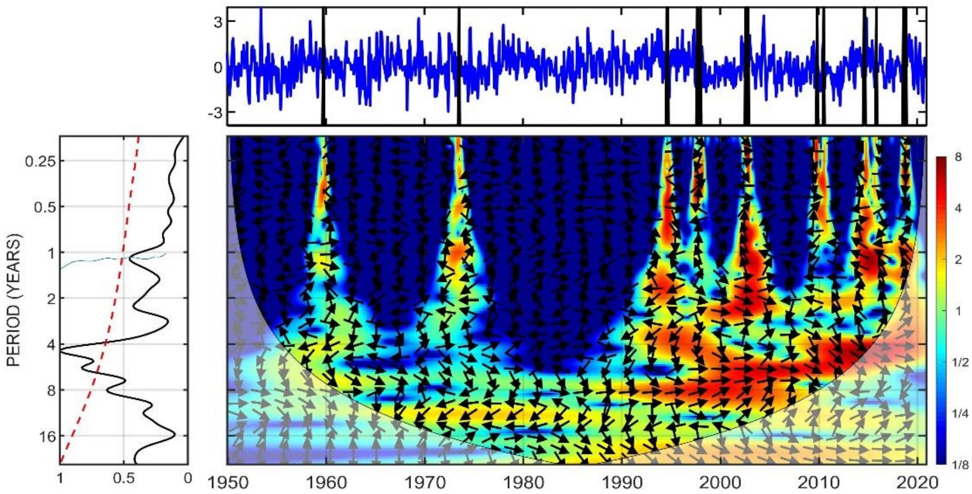


Fig. 7 Cross-wavelet analysis for Category 5 hurricanes and pdo.

In order to find the patterns that indicate the occurrence of category 5 hurricanes, it is necessary to analyze the C5H with climatic and oceanographic variables that provide information on the development of the C5H. To find the covariations that provide information on the patterns of when C5H occur, we have analyzed the cross wavelet between C5H and EP/NP. Fig. 6 show the results of the cross wavelet between C5H and EP/NP.

The global wavelet shows that the periodicities less than 95% of the confidence level are: 0.3, 0.6, 0.8, 1.1, 2.3, 5.7, 7.8, and 11.7 years.

It is seen in the central panel that the spectral power for these periodicities is intermittent, so this would indicate that these periodicities are related to the particular climatic and oceanographic conditions of occurrence of this C5H, so they would not be the patterns that would explain the high and low seasons of C5H. In addition, these periodicities cannot be used to make predictions of the occurrence of C5H for the following years.

The only periodicity more significant than 95% is again the periodicity of 4.4 years. The spectral power is very intense between 1990 and 2020. Between 1950 and 1990, the spectral power is weak due to the low number of C5H. However, the fact that there is a very intense covariance between the C5H and the EP/NP in the periodicity of 4.4 years could indicate that this periodicity could be one of the patterns that can explain the occurrence of the C5H and could be used to forecast the next C5H peak season. Fig. 7 shows the results of the covariance between C5H and PDO. The global wavelet cross wavelet shows that the periodicities less than 95% of the confidence level are: 1, 1.8, 2.5, 5.8, 8.5, 10.4, and 18.5 years. The multi-annual periodicities are intermittent, while the decadal periodicities (that is, 10.4 and 18.5 years), their spectral power is intense and the phase shows that there is a linear relationship (arrows from left to right), but these periodicities do not explain the occurrence of C5H. Again, the periodicity of 4.4 years has more than 95% of the confidence level and its spectral power is very intense. Furthermore, the phases show a linear relationship.

The El Niño phenomenon is significant in the development of hurricanes in the Atlantic and Pacific oceans. Figs. 8-10 show the results between C5H and Niño 1+2, Niño 3.4 and Niño 4, respectively. The global wavelets show that the periodicities less than 95% of the confidence level are 1.5, 2.8, 12.4, and 18 years; 1.5, 2.8, 5.8, 11.7, and 18.5 years; 1.5, 2.7, 6, and 11.7 years, respectively. The 4.4-year periodicity is the only periodicity greater than 95% of the confidence level in all cases and is the covariant periodicity of the C5H with the EP/NP, PDO, Niño 1+2, Niño 3.4 and Niño 4.

2.2 Forecast with Machine Learning Method

Although different methods exist to find correlated patterns in time series, we have chosen the Wavelet Transform (WT), see Refs. [12, 13] for more details about the method) in analysing the SST time series data because the wavelet spectra allows identification of intrinsic patterns of the phenomenon and facilitates the discovery of the characteristics of the phenomenons source.

We use the Morlet wavelet mother in the WT because of its high precision in resolving the patterns (periodicities) contained in the SST data and because it is a complex function that allows us to deduce the information on phase of the dominant timescale of the SST data.

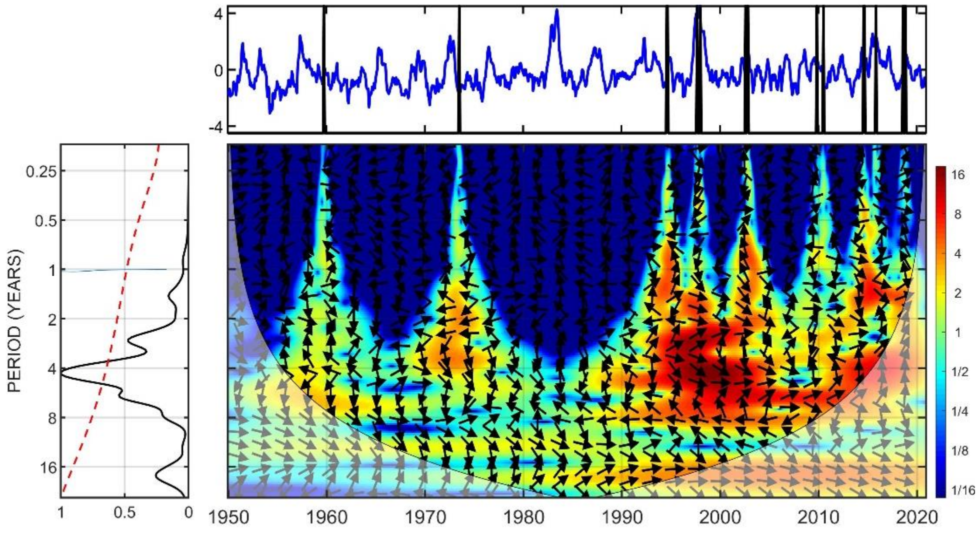


Fig. 8 Cross-wavelet analysis for Category 5 hurricanes and Niño 1+2.

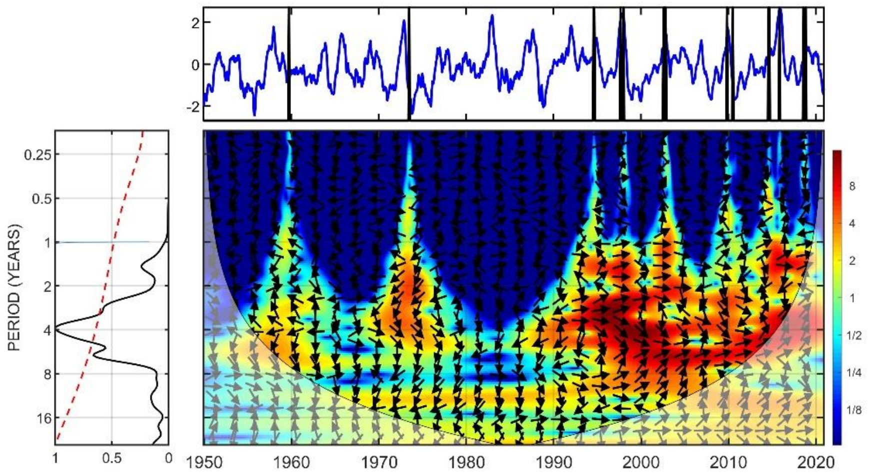


Fig. 9 Cross-wavelet analysis for Category 5 hurricanes and Niño 3.4.

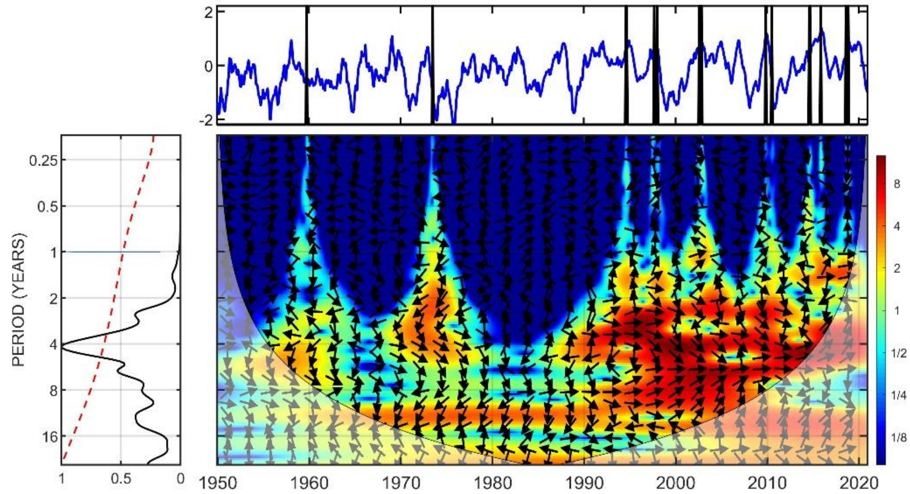


Fig. 10 Cross-wavelet analysis for Category 5 hurricanes and Niño 4.

The wavelet transform of a discrete time series y_n is defined as:

$$W_n(s) = \sum_{n'=0}^{N-1} y_n \psi_o * \left(\frac{(n'-n)}{s} \delta t \right) \qquad (1)$$

where *s* is the scale, *n* is the translation parameter (sliding in time) and the (*) denotes complex conjugation.

The decomposition of a signal (y_n) in channel or bandwidth can be obtained from inverse wavelet as:

$$y_n = \frac{\delta_j \delta_t^{1/2}}{C_\delta \psi_o(0)} \sum_{j=j_1}^{j_2} \frac{\mathrm{Re}(W_n(s_j))}{s_j^{1/2}} \qquad (2)$$

where j_1 and j_2 define the scale range of the specified spectral bands, $\psi_o(0)$ is an energy normalization factor, C_δ is a reconstruction factor, and δ_j is a factor for scale averaging.

For Morlet wavelet, $\delta_j = 0.6$, $C_\delta = 0{:}776$, and $\psi_o(0) = \pi^{-1/4}$.

The input data in the WT are the annual SST time series from 1950 to 2020. We have used the inverse transform to obtain the 4.4-year oscillation of the C5H from 1950 to 2020, and it is shown as a dotted red line in Fig. 11.

It is observed that the occurrence of the C5H occurs only in the positive phase of this periodicity would indicate that C5H is not a random phenomenon, but that under certain atmospheric-oceanographic conditions, it is when tropical cycles develop up to the top category and that they repeat approximately every

4.4 years.

Using Machine Learning method, we make a forecast for the next ten years in order to find the next high and low season for C5H. Machine Learning suggests that from 2020 to 2024, there will be a low season for C5H and that the new high season will be from 2025 to 2030.

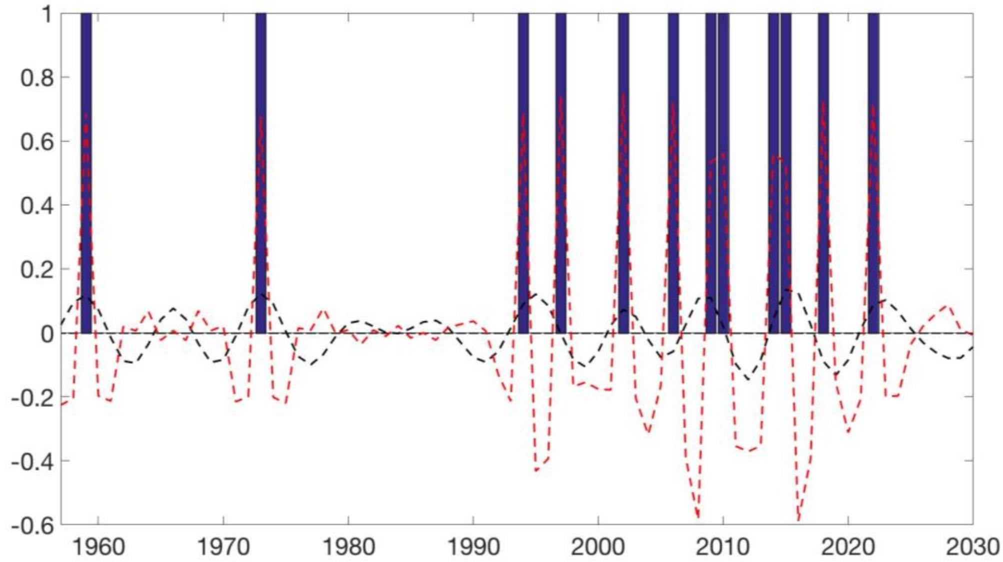


Fig. 11 Forecast of C5H.

3. Conclusions

The method to predict category-5 hurricanes in the Eastern Pacific assumes that the occurrence of these events is not absolutely random, but it is related by phenomena with oscillatory behavior. For our work, we consider the series of the temperature anomaly of the Pacific because their behavior is an important feature; high sea surface temperature is a necessary condition for the formation and development of hurricanes.

With the projection of the behavior of the periodicities in the future, it could be possible to predict the occurrence of forthcoming C5H in the Eastern Pacific. We have shown that 4.1 priodicity period is fundamental in forecasting fiture C5H.

Using Machine Learning Method, it is possible to obtain a reasonable prediction of Hurricanes or even other kind of aleatory phenomena.

Machine Learning Algorithms allow us to reproduce the time intervals of old hurricanes (1950-2020); on the other side these models suggest that a new phase of high activity Category 5 hurricanes will start in 2025 and run until 2030 — created by multi-annual climatic variations of the atmosphere-ocean coupled system.

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