Journal of Earth Science and Engineering 4 (2014) 572-579

Possibility of Predicting Category-5 North Atlantic Hurricanes

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Received: July 10, 2014 / Accepted: August 20, 2014 / Published: September 25, 2014.

Abstract: Category-5 hurricanes are the most devastating from the standpoint of human and economic losses. The occurrence of this kind of hurricane is believed to be of quasi-random nature, so it is very difficult to predict them well in advance. Warnings at this regard are generally given in the course of their development. We propose here, that there are some inherently periodicities of the phenomena that allow to predict category-5 hurricanes, even with some years of anticipation. For our study, we consider the North Atlantic category-5 hurricanes since 1920. We consider in this study data of the SST (sea surface temperature) of the North Atlantic Ocean as a representative parameter of hurricane activity. Then, by means of the wavelet analysis, we determine the dominant oscillation periods and establish correspondence rules using fuzzy logic. The wavelet power spectrum yields the following dominant periodicities: 0.5, 1, 3, 11, 22 and 32 years. The fuzzy logic searches for associations between the hurricanes occurrence and the behavior of the harmonics. Such correspondence rules lead us to restrict dates of possible hurricane occurrence. Interpolation of the periodic behavior allows for a good reconstruction of past hurricanes dates since 1920, as well as extrapolation to predict dates of occurrence in the future. We conclude that the conditions for the formation of the next category-5 hurricane in the North Atlantic may occur during the seasons of 2015-2017 with the highest probability in 2017.

Keywords: North Atlantic Hurricane, Predictions.

1. Introduction

The causes that control the frequency of occurrence of tropical cyclones are not well understood at present, in the sense, it depends on many factors. An average of 80 cyclones per year occur worldwide and are distributed in different regions; for example, in the North Atlantic occur in average 8.8 cyclones (of all categories) per year, this represents 11% of all cyclones that occur annually.

In the Pacific, the annual number of hurricane depends on the non-temporal fluctuations in the ocean-atmosphere relationship. Oscillation phenomena, such as El Niño, influence the trajectory and occurrence of tropical cyclones, increasing their appearance in about 28%. Recently, hurricane frequency in the Atlantic has been linked with the oscillations in the Pacific, although a direct connection was not found [1, 2]. Extreme events, such as CH5 (category-5 hurricanes) are considered as a random phenomena associated to complex physical configurations. Their occurrence is poorly understood, usually related to several variables, as solar activity cycles, climatic variations, anthropogenic processes, and so on. Solar phenomena completely dominate the interplanetary medium, thus defining the so-called space weather. Studies on solar-terrestrial relations indicate that extreme events in the Atlantic are also somehow linked to the behavior of solar phenomena.

A lot of phenomena in nature have a behavior that can be described by periodic functions; the behavior of the occurrence of category-5 hurricanes in the Atlantic is not an exception. The time series of hurricanes have inherently characteristic oscillatory periods that describe certain trend; these periods are linked by physical processes that are not yet clearly

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identified. Correlations are found in some periodicities present in hurricanes and other series such as sea surface temperature, SST (sea surface temperature) anomaly (shown in Fig. 1), as well as the AMO (Atlantic multi decadal oscillation) or even African dust storms from the Sahara [3, 4].

We performed the spectral analysis of the SST by means of wavelet transform, and then we analysis with fuzzy logic the behavior of periodicities with higher energy content in the Atlantic. These periodicities seek to characterize the temporal region where is possible to the formation of category-5 hurricanes in the North Atlantic; this refers to the definition of a temporary lapse in which the conditions for the formation of this kind of hurricanes is favorable. It is worth noting that this study is not addressed to determine how many hurricanes can occur, or precise days of the storm. In this work, we determine time intervals that define an active region for the occurrence of the next CH5 on basis of the information obtained from the membership functions.

2. Data and Analysis

The method we carried out to analyze the occurrence of category 5 hurricanes in the Atlantic is based on the quasi-oscillatory behavior in the temporal distribution of high category hurricanes, by relating their occurrence with the number of SST Atlantic surface temperature in order to obtain characteristic oscillation periods.

We analyzed the temporal distribution of hurricanes belonging to the HURDAT (Atlantic hurricane database) found at the website http: //weather.unisys.com/hurricane/. This catalog has 819 registered hurricanes that occurred in the Atlantic from 1851 to 2011. Many hurricanes do not hit land, but develop and disappear in open water; so many hurricanes that occurred in the late nineteenth century and early twentieth century are not registered in the database [5]. The first recorded category-5 event occurred in 1920. However, the most complete record of hurricane activity in the Atlantic began in 1966 with the use of satellite images in the NHC (National Hurricane Center) of USA. Since then, the estimation of the parameters and tracking of storms have become more accurately. The HURDAT database has are 105 category-4 hurricanes and 29 category-5, the latter are those who keep special interest because their high destructive effects, and they are the most energetic phenomena in the atmosphere, whose occurrence is assumed to be at random nature. In the absence of a physical theory that allows for the prediction of this aleatory phenomenon, we develop here some mathematical tool to approach the problem.

Among the several parameters affecting the formation of Atlantic hurricanes, a very important one is definitely the sea surface temperature of the Atlantic Ocean. The SST anomalies are very important in the generation of hurricanes, besides representing the highest temperatures in the sea surface, and they are also the engine that drives the storms and a crucial factor for maintaining their growth and existence. Furthermore, several studies have found correlation between the number of SST and the occurrence of hurricanes in the North Atlantic [6].

Fig. 1 shows the monthly values of time series of the SST anomaly in the Atlantic Ocean, covering the period from 1850 to 2013. The surface temperature data were obtained from the Atlantic ICOADS (International Comprehensive Ocean Atmosphere Data Set) of the NOAA (National Oceanic and atmospheric administration), available at the website http: //www.cdc.noaa.gov/coads/.

The middle panel of Fig. 1 shows the wavelet power spectrum of the SST series calculated with the wavelet analysis [7, 8]. In the global spectrum (right part in Fig. 1), the dominant periodicities of these series are observed. The more prominent periods found for forecasting hurricanes are: 0.5, 1, 3, 11, 22 and 32 years.

It should be mentioned that in a coherence analysis of Hurricanes vs SST, Ref. [3] found also the

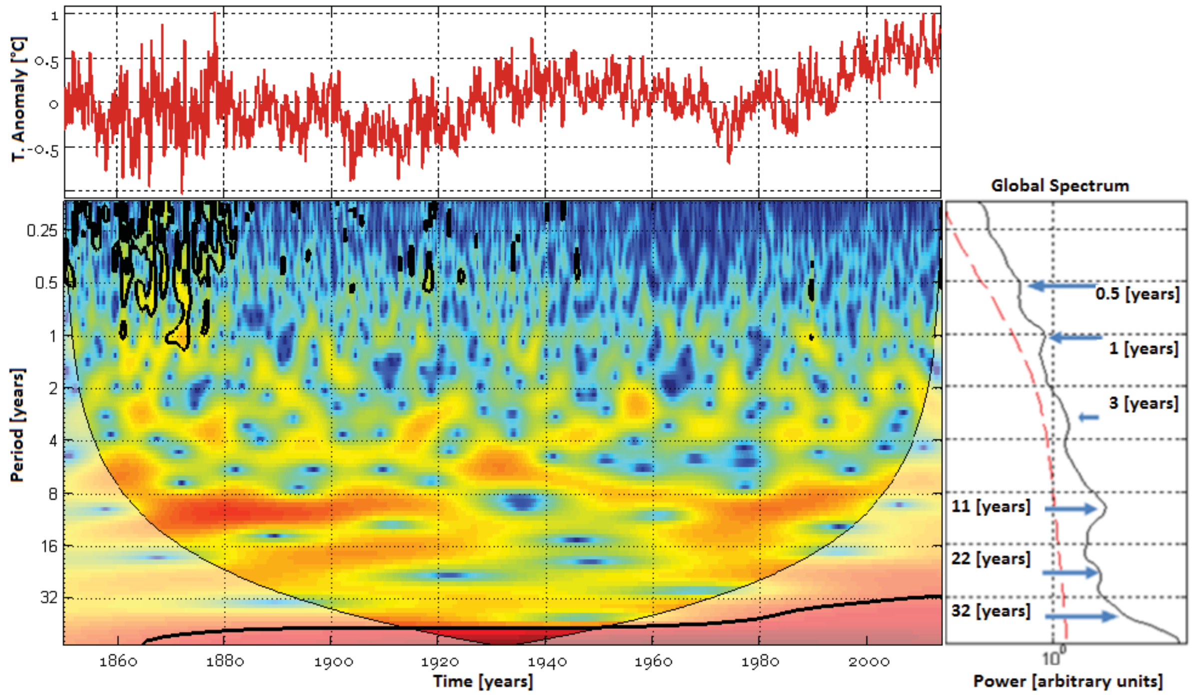

Fig. 1 Spectral Analysis: the Upper panel is the SST anomaly in the North Atlantic Ocean, the middle panel is the wavelet spectrum and the right panel is the global energy spectrum.

periodicities of 1, 3, 11, 22 yrs. On the other hand, if only the hurricanes are considered in the wavelet analysis, very close periodicities were obtained [9] using only the temporal distribution of the hurricanes series, independently of intensity and other characteristic of individual events: using hurricanes data from the National 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 coincident with those from the coherence analysis of SST versus hurricanes in Ref. [3].

In the previously mentioned work [9], the occurrence of these kind of hurricanes in the past was always found close to the maximum value (peak) or minimum value (valley) in all the studied periodicities, similarly to the case illustrated here in Fig. 2 for the specific periodicity of 22 years. With these systematic features and extrapolating forward in time periodic behavior, the authors computed time intervals where these features are met. In this way, it can be inferred 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 this paper, we abandon the empirical aspect, but we continue to use Wavelet Analysis, as the fundamental assumptions regarding the importance of the behavior of periodicities to describe the occurrence of hurricanes. We combine such analysis with Fuzzy Logic Analysis as described in Ref. [10]. Therefore, we compute here the time intervals where similar behavioral characteristics of periodicities are met, i.e., same phase in all groups for the events of the same type (e.g., the first hurricane in each group), and we do not limit the study to the imposition of empirical rules, as previously done by selecting only peaks or valleys.

In this study, we made a new classification of events, including the category-4 hurricanes listed in the HURDAT catalog before 1920. This is done in order to have more statistical information in our analysis, since there are only 29 category-5 hurricanes reported in the catalog. In Fig. 2, we show the proposed classification based on the periodicity of 22 years. Classification is carried out into eight groups, marked with green bars, such that groups are defined in a full oscillation of the periodicity, each one starting in the ascending peak phase. The Fig. 2 represents the occurrence of hurricanes of maximum intensity in the period 1851-2007. In Fig. 2, we indicate events occurred before 1920 with the purple bar and the legend “no clear data”. Since the well known current classification Saffir-Simpson dates of the 1960’s, those events were not classified as category-5 hurricanes in the HURDAT; for events before 1920, we only considered those of the highest intensity. The blue stars with a small pink color star inside show that the first events of each group are systematically in the ridge for chosen periodicity of 22 years. According to the group classification in Fig. 2, the next category-5 hurricane predicted in this work will be the first event of Group 8.

Group 0 indicates that there is no exact information of the first hurricanes during the corresponding 22 years cycle. The blue stars with a color purple star show that the first events of each group are systematically in the ridge for this specific periodicity of 22 years.

The procedure for calculating time intervals is to create membership functions for the periodicities with the highest energy in the wavelet power spectrum of the series of SST. We note that the fuzzy logic analysis sheds that the amplitude of the dominant periodicities and their behavior meets similar features (in both ascending or descending phase, or on the ridge or valley) during the occurrence of the selected event. This fact allows us for the retroactive estimation of the time intervals in which past hurricanes have occurred and prognosis of time intervals where future events may occur. For example, the first events of all groups are in the upward phase of the periodicity of 22 years of SST, while last hurricanes occurred in the downward phase of the same periodicity. For another periodicity, such as in 1 year, the first events occur mainly during the descending phase of a valley (Fig. 3). Gathering information on the behavior of different periodicities in the occurrence of CH5 in the past and making future projection of the oscillatory behavior of the periodicities, we infer that it is possible to predict the occurrence of events of the type (CH5).

The membership functions are usually constructed, or are proposed under the criteria of experts in the area of study and alternatively they can be calculated with mathematical algorithms for data analysis, that are

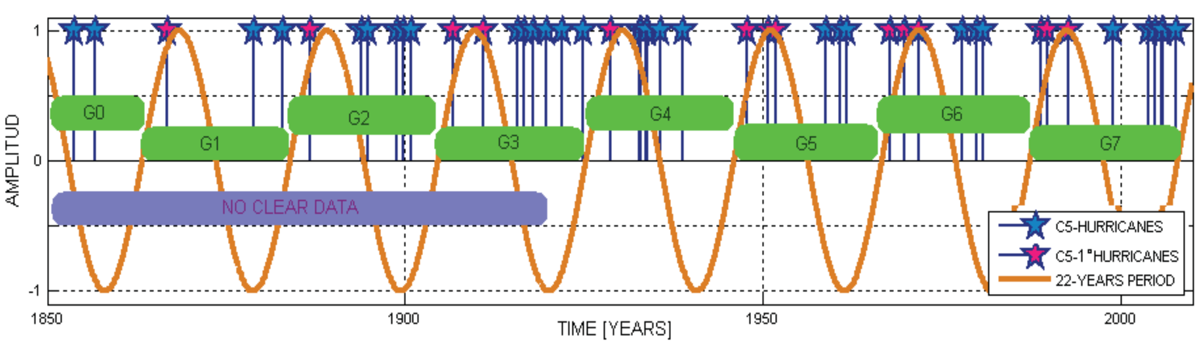

Fig. 2 Classification: Grouping of CH5 into eight groups according to their periodicity of 22 years (shown in the right panel of Fig. 1).

usually employed in control systems [11]. In our study, the membership function is the curve that describes to what extent the amplitude of a certain periodicity belongs by similarity to a subset of the amplitudes of the periodicity during the occurrence of a particular type of event (e.g., first events). The concept of fuzzy appears from the fact that a membership function may describe different CH5 with greater or lesser degree.

In our analysis, the membership function μ_A was constructed with the product of the equations of two standard Gaussian curves as expressed in Eq. (1), the mean and standard deviation are obtained with the data: the amplitude of the frequency and its derivative during the occurrence of the studied events.

$$\mu_A = \frac{1}{\alpha_A\sqrt{2\pi}} e^{\frac{-(t-\beta_A)^2}{2\beta_A{}^2}} \times \frac{1}{\alpha_{dA}\sqrt{2\pi}} e^{\frac{-(t-\beta_{dA})^2}{2\beta_{dA}{}^2}} \qquad (1)$$

Eq. (1) represents the membership function of the frequencies 0.5, 1, 3, 11, 22 and 32 years; α_A and β_A represent the average and standard deviation of the frequency amplitudes, respectively; α_{dA} and β_{dA} are calculated from the amplitudes and from the derivative of the periodicity, in both cases, the average and standard deviation are calculated with the data of the amplitudes of the frequency at the time of occurrence of the events of interest in the past, i.e., a CH5 known. Finally, t is the variable that represents the distribution of the amplitudes of the frequencies. We assume that our data can be approximated by a Gaussian bell, and the membership function is related statistically to data that we consider, and is not only built on empirical criteria. By using the derivative of the frequencies, the membership functions allow us to distinguish if the data of the amplitudes of the frequencies are in the ascending or descending phase.

Fig. 3 shows the membership function built for the first CH5 events and the periodicities of 22 years (upper panel) and 1 year (lower panel) of SST. In the upper part of Fig. 3, the blue line is a full period of the periodicity of 22 years with the normalized amplitude. In both graphs of Fig. 3, the membership functions for the events are the red lines. By definition, the membership functions have unitary maximum amplitude, where the value of 1 indicates the highest membership and 0 there is no membership (Mendel, 1995 [10]). In our aim to forecast, the amplitude of the membership function is calculated based on the prospective behavior of the amplitude of a certain

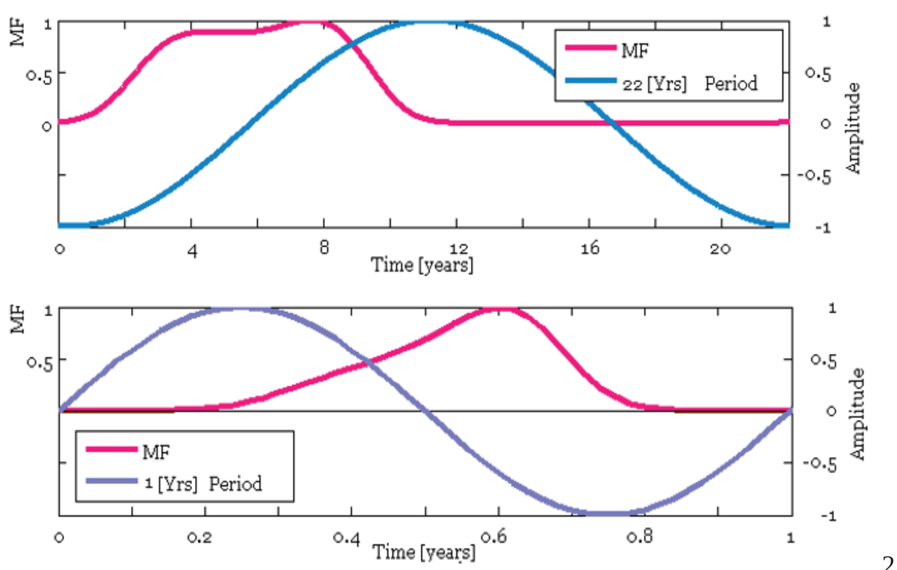

Fig. 3 Membership functions calculated for the first events with the periodicity of 22 years (top) and periodicity of 1 year (below).

frequency (periodic behavior in the future). Putting together the information of the membership functions calculated for all analyzed periodicities leads us to define time intervals for probable occurrence of a certain type of event.

Once it is built the membership functions for each frequency, the next step is to calculate the intersection of all of them, making the product (Eq. 2):

$$\Pi = \mu_{A\cap B\cap C\cap ...} = \mu_A \times \mu_B \times \mu_C \times ... \quad (2)$$

where, $\mu_{A\cap B\cap C\cap ...}$ denotes the intersection function and $\mu_A, \mu_B, \mu_C, ...$ are the membership functions of each of the periodicities and a given type of events.

3. Results

The product of the membership functions for all periodicities gives a function of time whose amplitude indicates the HC5 occurrence depending on conditions of all of the periodicities that are met together. On this basis, we calculated the degree of membership and potential regions where the quasi-periodic behavior indicates the time intervals where events may occur.

In Fig. 4, we show the reconstruction of occurrence intervals for the first events of the previous seven groups. The peaks in the blue lines of the Group 1 to Group 7 indicate the reconstructed regions where the events have occurred. It is noteworthy that, under the assumptions made, it is possible that not in all intervals a CH5 occurs as predicted by the membership functions, or at most one event took place as in groups 1, 2 and 4. The quasi-periodic behavior of the membership functions (Fig. 3) allows us to

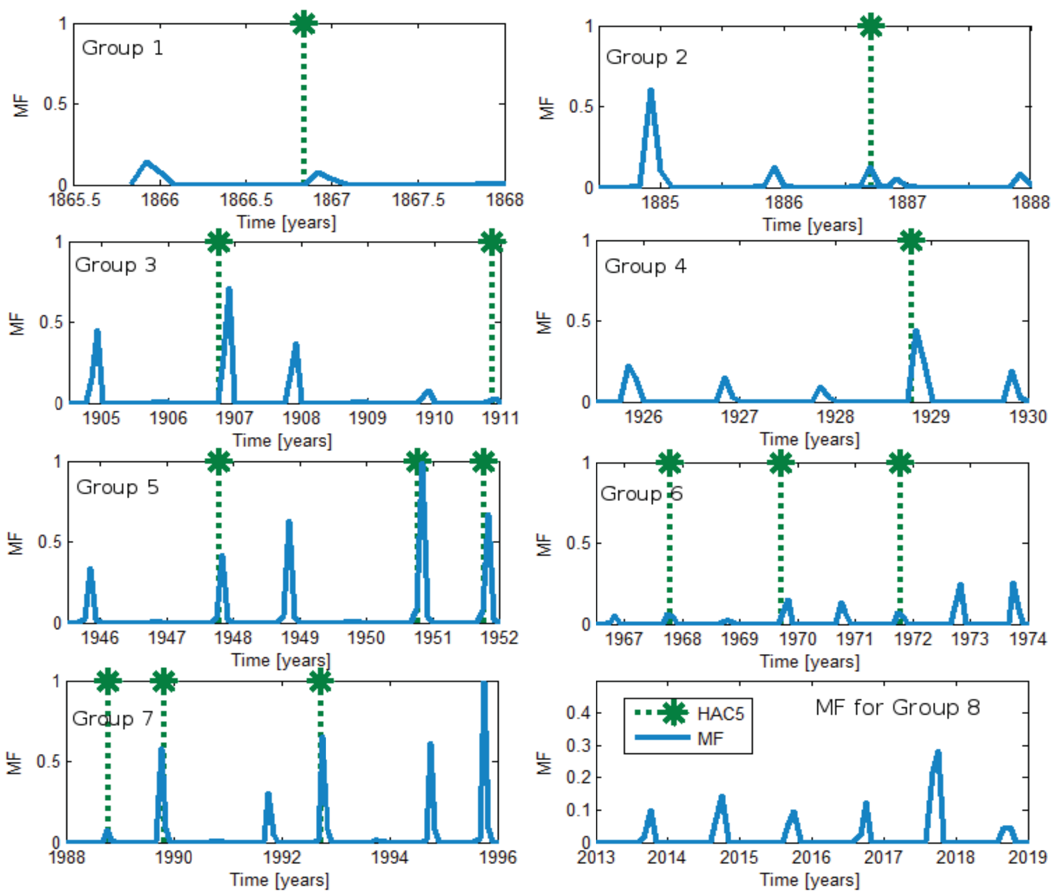

Fig. 4 Reconstruction and prognosis of the membership functions calculated for the first CH5 in 7 groups (Group 1 to Group 7) and the forecast for the first event of group 8.

Table 1 Possibilities for the first HC-5 of group 8.

Possibilities for the CH5 of Group 8		
Interval	Limits	
	Start	End
1	02.08.2013	02.11.2013
2	02.08.2014	02.11.2014
3	02.08.2015	02.11.2015
4	01.08.2016	01.11.2016
5	01.08.2017	01.11.2017
6	01.08.2018	01.11.2018

calculate the time intervals where events may take in the future. Panel 8 of Fig. 4 shows our forecast for the next category-5 hurricane, that is the first event of the current Group 8.

Taking into account that one of the more energetic periodicities is that of eleven years, as illustrated in Fig. 1, therefore, Fig. 4 gives also information about the behavior of membership functions constructed for the events in the previous cycles of solar activity. The considered conditions allow us to infer that if the occurrence of the CH5 can be described by fluctuations in solar activity, and if solar activity modulates SST on earth, therefore, the membership function, calculated with all periodicities, may contain information of the behavior of solar activity influence in terrestrial phenomena, indicating periods when solar activity is stronger and is able to influence the production of category-5 North Atlantic hurricanes.

4. Conclusions

The procedure to forecast category-5 hurricanes in the Atlantic also assumes that the occurrence of these events is not completely random, but it is controlled by phenomena with oscillatory behavior. For our analysis, we consider the series of the temperature anomaly of the Atlantic 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, we predict the occurrence of the following CH5 in the Atlantic. In Table 1 and Panel 8 of Fig. 4, we show the results of our forecasts for the next CH5, that is the first hurricane of Group 8.

We argue that there is a high possibility it will occur between August 2015 and October 2018, as showed in Group 8of Fig. 4 (first to fourth peaks of membership importance) or third to sixth rows in Table 1. The possibility of occurrence in 2019 is low because their memberships are relatively small (Panel 8 of Fig. 4). According to the Panel 8 of Fig. 4, the best forecast is between August and November 2017. Furthermore, we note also hurricane seasons in which no phenomena of high intensity are expected: for example, our method allow us to predict that no expected category-5 hurricanes before the season of 2011 would occur, and effectively there were not events in the period from 2007 to 2011. A detailed study of the problem has been given in Ref. [12].

Acknowledgments

We thank the support of UNAM (DGAPA-PAPIIT) by means of grant IN106214.

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