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Nonlinear Processes in Geophysics
Discussions
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Interactive comment on "Nonlinear analysis of the occurrence of hurricanes in the Gulf of Mexico and the Caribbean Sea" *by* Berenice Rojo-Garibaldi et al.

Berenice Rojo-Garibaldi et al.

dsalas@unam.mx

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Answers to comments of referee 2

Concerning the manuscript itself, I am not a native English speaker, but in my opinion the English needs some revision. The Results section is difficult to follow. The amount of information is huge and sometimes it seems that parameters are calculated without rhyme or reason

An apology for the English version of the manuscript, the manuscript was reviewed by an American English speaker. Once the modifications suggested by the reviewers

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Discussion paper

have been satisfactory made, they will sent it to a professional editing system for their correct presentation in English.

Data set description. I found this section quite discouraging as no information on how the time series was built. For example, are you using yearly data? Only landfall hurricane data were used?, If this is not the case, which is the area for hurricane detection? will assume that you cane data were used?, If this is not the case, which is the area for hurricane detection? How Fernandez et al data were added to HURDAT data base? So, in the following I are using yearly data since 1749 to 2012 (264 data points).

The way in which the time series was constructed is explained in Rojo-Garibaldi et al. (2016):

“a historical database (1749-2012) of hurricane occurrences in the Gulf of Mexico and the Caribbean Sea was built. To do this, we started with the HURDAT hurricanes time series and then analyzed historical re- ports of hurricanes provided by ships that passed near the re- ported hurricanes; data from aerial surveys of recent hurricanes beginning in 1944 were also used. This information, plus that of Fernández-Partagás and Díaz (1995a, 1995b, 1996a, 1996b, 1996c, 1997 and 1999), was added to the HURDAT time series to build a new and longer time series of hurricane occurrence in the Gulf of Mexico and the Caribbean Sea. We considered the data valid when the hurricane was reported by more than three different data- bases; we analyzed the path of the hurricanes to avoid counting a hurricane more than once when it was reported in different places with different times but corresponding to the same hurricane.”

Regarding how the data of Fernández-Partágas and Díaz were added and processed, it is explained in detail in the HURDAT page, since it published its data along with a series of articles specifying the methodology for each case, since the publication of its database was done by sections of years. The study area is the Gulf of Mexico and the Caribbean Sea, all hurricanes in that region are considered, observed on land or in water. Annual data are being used (264 data), apparently few data, but using the criteria of Eckmann and Ruelle (1992) and Ruelle (1990). The result showed that they are sufficient for the analysis that was intended to be performed. On the other hand, it is important to mention that it is the longest series of hurricane occurrences in the Gulf of Mexico and the Caribbean Sea, up to this moment.

One of my main concerns is that you are using a time series with some trend. You need to show the stationarity of the series. There is a significant body of literature on nonstationary tests that often deals with the division of the time series into several windows where a common statistical property is measured and compared among the different divided parts of the series. You may plot the probability density function for half of the time series and for the full pack, or you may detrend the time series, for example.

Figure 1 shows the time series and its tendency, in most of the analyzes it is commonly used to use series without trend, like in spectral analysis, non-linear analysis, etc; since leaving the trend gives a residual that masks the results. In our study we removed the trend. We appreciate the observation and we included a paragraph making explicit that the tendency to the series was removed.

The order of figures seems to me quite confusing. For example, the Poincare map is shown before the embedding dimension is calculated. Taking into account that m is larger than 3, the section obviously does not give any information at all. It is just a cloud of points, but not due to the chaotic nature of the attractor but as it is a 2D projection of an m-1 dimension set.

We can change the order of the results and consequently the order of the figures. Our objective was to present the evidences of possible existence of chaos in the series and to apply more robust methods, to corroborate this, as it is said in the following paragraphs:

“The optimal time lag (τ) obtained from Fig. 2 was equal to 9. In our case the hurricane dynamics were not distinguish through with the phase diagram; however, since any hurricane trajectory starts at a close point location on the attractor dataset that diverges exponentially, it is a primary evidence of a chaotic motion according to Thompson and Stewart (1986). Another way to visualize the dynamics of the system is through the Poincare Surface Section (Fig. 3), which helped us to observe the presence of chaos involved in our data. It was observed that the points are scattered in the constructed plane, which indicates that there is a chaotic behavior. However, the most robust method to identify chaos within the system is the exponent of Lyapunov, before obtaining the exponent it was necessary to calculate the time lag using the Theiler window and the embedding dimension"

On the other hand, if the Poincare diagram does not show "a cloud of points" then we can say that there is no chaotic nature. Finally, a two-dimensional scan is the first to say something about the chaotic nature of the data.

The obtained embedding dimension m=4 or 5 is said that correspond to a fractal dimension D=2.2 (m=2D). This corresponds a minimum number of data points (Eq.(9)) N1âĂž159 which is more than half of the total length of the data set used in this paper. Other authors (Bountis et al. 1993) use a different formula m=2D+1 and Nb10**(2+0.4D) which extends the minimum number of data points beyond the actual length of your time series. In resume, your data set is too small for this kind of nonlinear analysis.

In fact, there are other authors that use different formulas or criteria to estimate the minimum number of points that are required to do a non-linear analysis in time series. We use the criteria of Eckmann and Ruelle (1992) and Ruelle (1990), which is well known and used in this type of analysis. Here it is important to mention that it is true that our references are somewhat outdated, but they correspond to quotations from widely used and proven methods, they are not new methods or proposals of novel methods, our objective is not to show that novel methods are used, the main objective is to understand why hurricanes have the behavior that makes them so special and difficult to predict; even with all the technology and theoretical methods used for its detection and prediction. That's why we applied well-known methods that are not subject to doubts. Regarding a m = 2D, it must be obeyed by the laws of embedding that m > 2Df, but in the case of the correlation dimension, it is sufficient that m > Df (Sauer and Yorke, 1993; Kantz and Schreiber , 2004).

Figure (7) should appear before than others, and the slope should saturate for the embedding dimension calculated previously (m=4,5) which is not the case here. Any explanation? What's the difference with Fig. (9)?

A very pertinent observation, since Figure 9 includes the information of Figure 7, the latter can be removed. With respect to the slope, which must be saturated for the previously calculated dimension (m = 4.5), which apparently is not the case here, the explanation is only for the shape of the figure.

In Fig. (9) I cannot understand how the linear fitting is done. Why the lines drawn in panel (a) do not match the slopes marked with points. The saturated values on top of the figures should not be takin into account.

Figure 9 on the left side shows the exploratory analysis of the possible dimensions of the tractor, which were obtained with the help of figure 8 which is the correlation dimension, in many of the known literature it is known that this only gives an approximate dimension and therefore it is necessary to use the correlation integral, which is figure 9, on the right side we are putting the slope that best fits the dimensions of the attractor. The adjustment of the slope was made according to the method developed by Grassberger and Procaccia (1983a, 1983b). The largest Lyapunov exponent as a function of the embedding dimension m and the time delay tau may show the deterministic nature of the time series. When the dimensionality of the embedding space is reduced, the exponent is expected to increase for a deterministic system because the attractor occupies a larger portion of the available space, which does not happen for a random signal. You may compare your results with a random time series (just move randomly the data points within the time series). I think this is important as your

Lyapunov exponents are quite small.

We appreciate the comment and we did this analysis.

One of the interesting applications of these nonlinear techniques is their use to forecast the hurricane occurrence. This will allow to (1) know if the attractor reconstruction is correct, and (2) compare this method to classical linear time series analysis as ARMA estimators, for example. The first point should be mandatory.

We appreciate the comment. With respect to the first point, different types of analysis were made; in fact, they seem redundant, but it was one of our concerns to have certainty in estimating the attractor. With respect to the second point in Rojo-Garibaldi et al. (2016) a part of the linear and non-linear analysis was done, to the time series applying spectral analysis, we included the reference and a comparison with the results obtained in Rojo-Garibaldi et al. (2016).

Minor points:

We appreciate the comments and we made them punctually throughout the text.

Line 1 page 2. "...have usually been performed with linear-type analyses..." needs a reference.

HURDAT reanalysis project needs a reference.

References to nonlinear analysis along the paper are very old. Please, look for new ones and show other example where these kinds of techniques were applied.

Some of the explanations given along the text, or even formulae in the results section are naïve and should not appear or just referenced. Otherwise, you could move some of them to an Appendix for example.

Along the text time delay is written sometimes as r and in other occasions as tau. Fig.2 is a mess and does not give any information as it is drawn.

Conclusions section is not admissible. You need to resume and explain why your method is better than others and what is new here. You need to strengthen the deterministic nature of your time series if compared to a random signal. If the time series is deterministic, what is the underlying physics behind this fact?

In this case, it is not of our interest to show that the methods that were applied here are better than others, our interest concerns the chaotic nature of the hurricanes. What is important here is to show that hurricanes show a different behavior when they are analyzed in an individual form that when they are studied collectively, that corresponds to what is called state in a chaotic edge. We believe that this is important for future hurricane studies, their individual and collective behavior should be studied separately.

References:

Bountis, T., L. Karakatsanis, G. Papaioannou, and G. Pavlos. 1993: Determinism and noise in surface temperature time series. Ann. Geophys., 11, 947-959

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