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# Hurricanes in the Gulf of Mexico and the Caribbean Sea and their relationship with sunspots

Berenice Rojo-Garibaldi [a], David Alberto Salas-de-León [b,*], Norma Leticia Sánchez [c], María Adela Monreal-Gómez [b]

[a] Posgrado en Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, Av. Universidad 3000, Col. Copilco, Del. Coyoacán, Cd.Mx. 04510, Mexico

[b] Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, Av. Universidad 3000, Col. Copilco, Del. Coyoacán, Cd.Mx. 04510, Mexico

[c] Dep. El Hombre y su Ambiente, Universidad Autónoma Metropolitana, Calz. del Hueso 1100, Del. Coyoacán, Villa Quietud, Cd.Mx. 04960, Mexico

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ABSTRACT

We present the results of a time series analysis of hurricanes and sunspots occurring from 1749 to 2010. Exploratory analysis shows that the total number of hurricanes is declining. This decline is related to an increase in sunspot activity. Spectral analysis shows a relationship between hurricane oscillation periods and sunspot activity. Several sunspot cycles were identified from the time series analysis.

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## 1. Introduction

In recent years there has been a broad consensus that the increase in hurricane number and intensity is a result of global warning effects in the Atlantic Ocean (Webster et al., 2005; Venkataramanan, 2011; Emanuel, 2013; Estrada et al., 2015). An increase in solar activity contributes to ocean warming and alters atmospheric circulation (Hodges and Elsner, 2011); thermodynamic air-sea disequilibrium and thermodynamic efficiency control the tropical cyclone potential intensity (Wing et al., 2015). Therefore, there is reason to believe that potential hurricane energy is related not only to solar activity but also to its occurrence. Other studies postulate that there has been a decrease in the total number of hurricanes but an increase in hurricane intensity, resulting in a higher number of category 4 and 5 hurricanes (Zhao and Held, 2010; Mallard et al., 2013; Murakami et al., 2012; Briggs, 2008; Held and Zhao, 2011). However, the current understanding of tropical cyclone generation and frequency is still limited (Nitu et al., 2013). Several studies (Elsner and Jagger, 2008; Jagger and Elsner, 2010; Hodges and Elsner, 2011; Elsner et al., 2009) found a link between the frequency of hurricanes and sunspots. In this study, we are interested in the occurrence of hurricanes in the Gulf of Mexico and the Caribbean Sea and in the connection between their occurrence and sunspots. Although some studies have already demonstrated the existence of a connection between sunspots and the frequency and intensity of hurricanes, some results sometimes show a direct connection, others show an inverse connection, and some describe a more complex relationship. An important part of this study is that we explain the origin of these relationships.

Mendoza (2011) compiled studies on cosmic rays, sunspots and hurricane occurrences in the Atlantic and Pacific and found a link between the frequency of hurricanes and sunspots. Pérez-Peraza et al. (2008b), Elsner and Jagger, (2008) and Mendoza and Pazos (2009) found periodicities that matched the number of sunspots and solar magnetic cycles with hurricane occurrences. Other works (Poey, 1873; Benestad, 2002; Hodges and Elsner, 2011) indicate that hurricane activity in the Atlantic is coincident with several solar cycles. Some of these studies (Hodges and Elsner, 2011) have been completed with time-series data of hurricane occurrences since 1851 using Hurricane Databases (HURDAT) as a source in the North Atlantic basin. In this study, we use HURDAT as main data source but added more years of information from historical records collected by different authors (Poey, 1855; 1862; Dunn and Miller, 1960; Ludlum, 1963; Millas, 1968; Roth, 1997a, 1997b; Murnane et al., 2000; Liu and Murnane, 2004; Chenoweth,

* Corresponding author.
*E-mail address:* dsalas@unam.mx (D.A. Salas-de-León).

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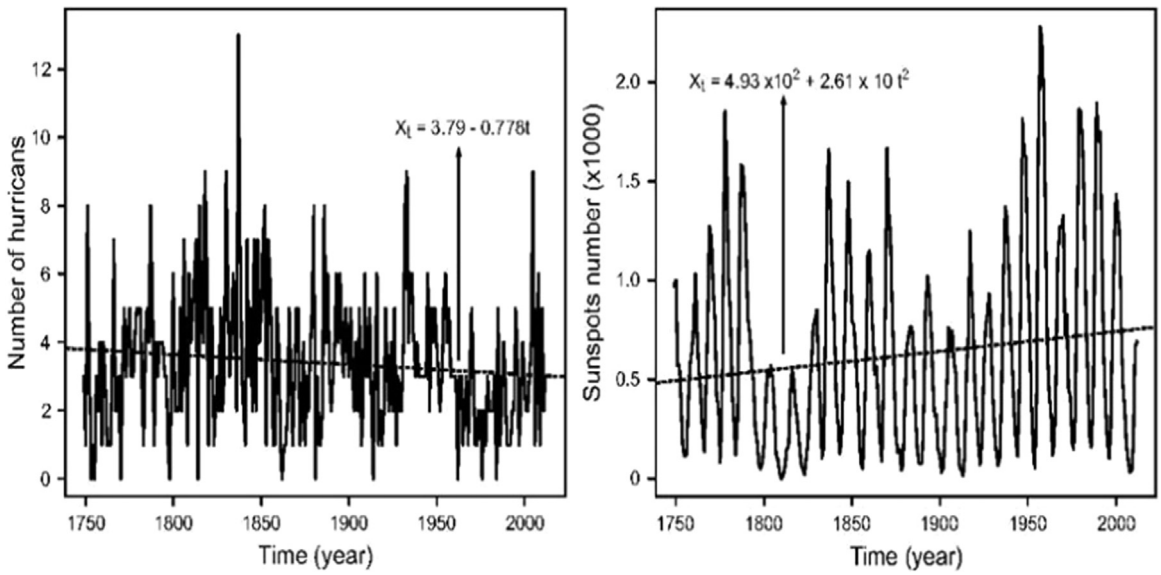


**Fig. 1.** Hurricanes (left panel) and sunspots (right panel) from 1749 to 2012. The red line shows the linear trend.

2006; Emanuel, 2005), providing a larger hurricane time series for the Gulf of Mexico and the Caribbean Sea.

## 2. Data and methods

### 2.1. Hurricanes and sunspot series construction

The number of sunspots was obtained from the Solar Influences Data Analysis Center (SIDC) of the Solar Physics Department of the Royal Observatory of Belgium. Additionally, 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 reports of hurricanes provided by ships that passed near the reported 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 databases; 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.

### 2.2. Spectral analysis

Four different methods were used for spectral analysis: Blackman-Tukey, maximum entropy method, multi-taper and wavelet; the first three are complementary (Ghil et al., 2002). The Blackman-Tukey method is useful in identifying the most representative periods of a series (Ghil et al., 2002); however, the spectral resolution of this method is generally poor when the volume of data, and hence, the window is small (Rojas and Bravo, 1999; Ghil et al., 2002). Therefore we used it in parallel with the maximum entropy method (MEM) and multi-taper method (MTM) (Ghil et al., 2002). MEM gives better results in short time series (Rojas and Bravo, 1999), as is the case in this study, and it is also able to analyze with better accuracy periodicities next or equal to the total length of the series (Rojas Bravo, 1999; Ghil et al., 2002). Multi-taper is a useful tool for spectral estimation (Thomson, 1982; Percival and Walden, 1993) and reconstruction of time series signals (Park, 1992) whose spectrum can contain both broadband and linear components (Ghil et al., 2002). This method reduces the variance of the spectral estimation using a small set of tapers or windows (Thomson, 1982; Percival and Walden, 1993; Ghil et al., 2002). Wavelet analysis is widely used for non-stationary time series, providing information about not only where the most representative periods are but also when they appear, how long they last and if the relationship is linear or more complex (Hubbard, 1996; Mallat, 1998; Torrence and Compo, 1998; Weedon, 2003).

## 3. Results and discussion

### 3.1. Trends in the number of hurricanes

The *t* test of the linear regression indicates that the regression is not linear but that the analysis of residue is equally distributed on both sides of zero, showing the stability of the variance and indicating that the straight line is a good model. Because we do not want to predict the future behavior of the hurricane number with a linear regression but rather to observe their behavior over the duration of the time series, the result of the residue analysis is enough to ensure that the hurricane number is actually decreasing in time. The linear tendency for hurricanes during the time series from 1749 to 2012 shows a downward trend (Fig. 1); several authors postulate that the number of tropical cyclones in the Atlantic is increasing (Emanuel, 2005; Webster et al., 2005; Trenberth, 2005; Elsner, 2007). In our time series, it is possible to see an increase in the occurrence of hurricanes from 1960 to 2012; nevertheless, it is important to remember that this series is only for the Gulf of Mexico and the Caribbean Sea, not for all of the Atlantic. Hodges and Elsner (2011) use Chenoweth's time series (2006) to study hurricanes in the Gulf of Mexico and mentioned that it is possible that more data on hurricane occurrence could be collected towards the end of the record than at the beginning, which would naturally result in an upward trend in the number of hurricanes; even if underestimating the number of hurricanes in the early years, at least partially, the trend should increase with a lower slope than what we obtained. In this study, we have more data, but if we look only at the part of the time series that Hodges and Elsner (2011) studied, an increase is observed (Fig. 2); however, when analyzing the entire time series built for this study, i.e.,

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