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Analysis of precursors of tropical cyclogenesis during different phases of the solar cycle and their correlation with the Dst geomagnetic index

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ABSTRACT

Three tropical cyclogenesis precursors, (absolute vorticity, relative humidity, vertical shear)and, the combined Genesis Potential Index are investigated in order to analyse their behaviour during three different phases(descending, minimum and ascending) of the solar cycle. The correlation between these tropical cyclogenesis precursors and the Dst geomagnetic index is also assessed, with the main finding being that the correlations between both the Genesis Potential Index and the vertical shear with the Dst index are statistically significant. This result suggests that the relationship between geomagnetic activity and tropical cyclones might be modulated by the influence of geomagnetic activity on the vertical wind shear.

1. Introduction

The variability of tropical cyclones (TCs) is of considerable interest, not only because these climate phenomena play an important role in global atmospheric circulation, but also because of the widespread social and economic impacts of their landfall.

In the case of Mexico, its location between the two important basins of the North Atlantic and the Eastern Pacific oceans in which tropical cyclones develop on an annual cycle, make this country of particular interest to climatologists. In the 2013 hurricane season, damage was reported due to strong winds, flooding, and landslides (Beven, 2014; Pasch and Zelinsky, 2013; Brown, 2013) at a total cost off more than 4 billion dollars,more than 3 million people were affected in Mexico alone.

Nowadays, weather forecasting models are able to predict the evolution of TCs a few days before their development, allowing most of the population at risk to be alerted, with the aim to reducing the potential for damages, this being one of the main areas of concern in the study of TCs climatology.

Of the issues that remain unclear in TCs activity, the effect of solar activity have received a fair amount of attention over the past decade and several authors have suggested the existence of such an effect. For instance, Elsner and Jagger (2008), Elsner et al., (2010), Hodge and Elsner (2012), Hodges et al. (2014), linked the number of sunspots with hurricane frequency; Kavlakov and Elsner (2008) found a statically significant correlation between geomagnetic activity in terms of the Kp index and hurricane intensity over the Atlantic; additionally, several disturbances in geomagnetic activity as well as changes in the number of sunspots and in the intensity of cosmic ray were observed prior to TC genesis by Perez-Peraza et al. (2008).

Mendoza and Pazos (2009), found that the greatest significant correlations occur between Atlantic and eastern Pacific hurricanes and the Dst geomagnetic index. Most importantly, both oceans present the strongest hurricane–Dst relationships during the ascending phases of odd-numbered solar cycles and the descending phases of even-numbered solar cycles (Type 2). Conversely, for the ascending phases of even cycles and the descending phases of odd cycles (Type 1) the relationships are weaker, showing the existence of a 22-year cycle. They also found that Atlantic hurricanes have a negative correlation with the Dst index while Pacific hurricanes have a positive correlation for Type 2 solar cycles. These authors suggested that this behaviour could be due to differences in cyclogenesis and the presence of large-scale climatic phenomena such as the NAO, SOI, etc.

The formation of TCs is related to six averaged parameters (Gray, 1968): the Coriolis parameter (f), related to a tropical disturbance developing at least 5° away from the Equator; low-level relative vorticity (ζ); inverse of the tropospheric vertical wind shear (wind shear values below 10 ms^{-1} between the surface and upper troposphere); thermal energy of the ocean (sea surface temperature greater than 26 °C up to 60 m below the surface); difference in equivalent potential temperature between the surface and 500 mb (conditional instability); increase of relative humidity in the mid-troposphere (700 mb). In the Atlantic Ocean basin, African easterly waves are considered the main precursor of

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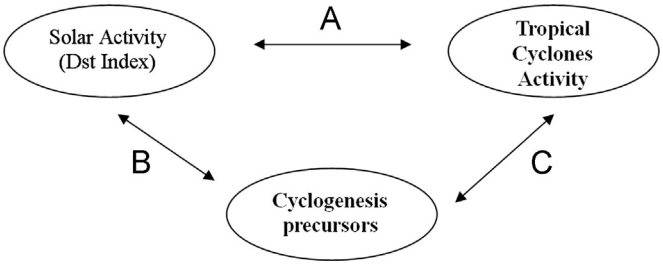

Fig. 1. Framework of the investigation.

TCs (Elsner and Birol, 1999), and their intensity and tracking is being related to certain phases of El Niño/Southern Oscillation (ENSO), the Atlantic Multidecadal Oscillation and the North Atlantic Oscillation (Elsner, 2003). Eastern Pacific tropical cyclogenesis is related to strong easterly waves crossing the mountains of Central America and the presence of low-level monsoon westerlies. TCs frequency in this basin is strongly related with ENSO activity (Camargo et. al, 2008) .

For this study, we chose atmospheric variables related to some of the parameters mentioned above, namely absolute vorticity (η) , vertical wind shear (V_{shear}) and relative humidity ($\mathscr{H}$), according to the availability of data.

Furthermore, as means of approximating the TCs climatology, we calculated the genesis potential index (GPI), developed by Emanuel and Nolan (2004). Several authors have shown evidence of the efficiency of the GPI for modelling TCs climatology (Bruyère et al., 2012; Camargo et al., 2007a, 2007b).

In Fig. 1 is shown the framework of the investigation, the relationship between solar activity, tropical cyclone activity and atmospheric variables linked with tropical cyclogenesis or cyclogenesis precursors (CPs).

Relationship A, was established by Mendoza and Pazos (2009), who proposed the existence of the 22-year hurricane cycle. In the present study, we attempted to establish relationship B, by calculating the correlation between the Dst index and the cyclogenesis precursors (CPs), and relationship C by comparing the GPI index and the cyclogenesis recorded by the National Hurricane Center (NHC) on the first day of a tropical depression, because all the CPs are considered in the calculation of GPI. A secondary objective of this study was to extend the work of Mendoza and Pazos (10) by obtaining the correlation between Dst and the atmospheric variables involved in the genesis of TCs, in order to identify more of the elements involved in the relationship between solar activity and TCs.

2. Data and methodology

Data were obtained from the Earth System Research Laboratory, Physical Division and the National Center for Atmospheric Research, NOAA-CIRES 20th Century Reanalysis version 2 data. The area under consideration was a grid bounded by 6°–34° N, 120°–10° W, which includes the area of cyclogenesis of the Eastern Pacific and the North Atlantic, with a resolution of 1.5°, and with limits of 1000 and 70 mb of pressure.

The GPI was defined by:

$$\mathrm{GPI} = |10^5 \eta|^{3/2} \left(\frac{H}{50}\right)^3 \left(\frac{V_{pot}}{70}\right)^3 (1 + 0.1 V_{shear})^{-2} \quad (1)$$

where η is the absolute vorticity at 850 h Pa (s^{-1}), $\mathscr{H}$ is the relative humidity at 600 h Pa, V_{pot} is the maximum potential intensity ($m\,s^{-1}$), and V_{shear} is the magnitude of the vertical wind shear between 850 h Pa and 200 h Pa ($m\,s^{-1}$) (Camargo et al., 2007a, 2007b).

The V_{pot} calculation was made using the MATLAB code available on the Kerry Emanuel's web page.

Fig. 3. Sunspot numbers for solar cycles 19–23, separated into Type 1 and 2, respectively.

Table 1
Periods for Type 1 and Type 2 solar cycles.

Type 1	Type 2
1958–1968	1969–1979
1980–1989	1990–2000
2001–2012	

Table 2
Three-year composites for each solar cycle.

Period	Descending phase	Minimum phase	Ascending phase	Cycle type
1958–1968	1958–1960	1963–1965	1966–1968	1
1969–1979	1969–1971	1974–1976	1977–1979	2
1980–1989	1980–1982	1984–1986	1987–1989	1
1990–2000	1990–1992	1994–1996	1998–2000	2
2001–2012	2001–2003	2007–2009	2010–2012	1

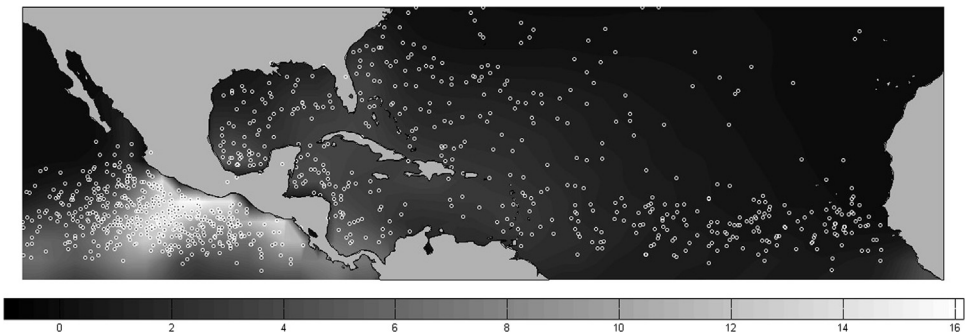

Fig. 2. Tropical cyclogenesis in the North Atlantic and Eastern Pacific basins (white dots), and the GPI values for the period 1957–2012. The bar at the bottom of the figure shows the key used for the shading.