

The Effects of Space Weather on Hurricane Activity

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1. Introduction

The Sun is a variable star which emits electromagnetic radiation, mass in the form of transient and continuous phenomena (the solar wind) and energetic particles. The solar wind is plasma that drags the solar magnetic field throughout the interplanetary space beyond the Pluto orbit (which is at ~ 40 AU, being 1 AU the Sun-Earth mean distance), forming a region that is known as the heliosphere. Observations of the Voyager 1 spacecraft indicate that the heliospheric termination shock is at ~ 94 AU (e.g. Webber et al., 2009).

The bodies embedded in the heliosphere react to the impact of solar activity according to their characteristics, i.e. whether or not they have intrinsic magnetic fields, ionosphere or neutral atmosphere. In particular the Earth responds to solar variability through geomagnetic activity, variations of the high atmosphere, and possibly changes of weather, climate and biota.

1.1 The impact of solar activity on planetary bodies

The changes in solar activity modulate all the space phenomena that impinge on the planetary bodies, including a flux of charged high energy particles coming from outside the heliosphere, the galactic cosmic rays (CR). The interplanetary solar magnetic field (IMF) constitutes a barrier for the CR, which consist mostly of high energy protons (energies up to $\sim 10^{11}$ GeV) produced by various stellar processes in our galaxy, mainly supernova remnants; although CR of energies $\sim 10^{10}$ - 10^{11} GeV are thought to be extragalactic. At the time scales of the 11-years solar cycle the CR show an approximate anticorrelation with the sunspot numbers (SN) (e.g. Caprioli et al., 2010).

The main large-scale solar phenomena that most affect the planetary bodies are the solar flares, the coronal mass ejections (CMEs) and the fast solar wind coming out of coronal holes. They impact our planet at different times scales: the short-time scales of a solar storm (hours to few days), or the solar cycles in the scale of years like the 11 or 22 years.

During a solar storm (see Figure 1), solar flares send electromagnetic radiation (X-rays, EUV, visible, radio bursts) that reach eight minutes after being produced the terrestrial atmosphere and affect it during 1 to 2 days. The combined effect of flares and CMEs produce high energy solar particles (~ 100 MeV) (also called solar cosmic rays or proton events) that arrive between 15 minutes and few hours after being produced and affect the

atmosphere for some hours to few days; some proton events have very high energies (few GeV) similar to those of the CR, they are the so-called ground level enhancements. The CMEs and solar wind produce low and medium energy particles (up to 100 keV) arriving after 2 to 4 days and affecting the atmosphere for some days. In Figure 1 we can appreciate the effect that these emissions cause on man-made technology.

Also the Forbush decreases (decreases of the CR fluxes along few hours) are produced by CMEs and high speed wind streams.

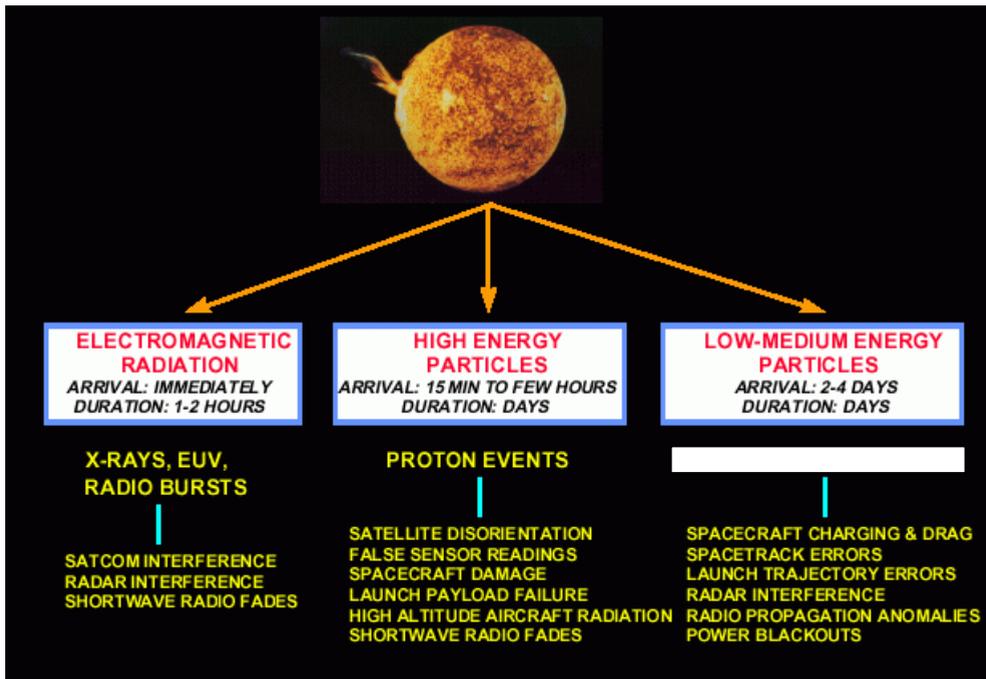


Fig. 1. A scheme relating the solar storm with their impact on the Earth. Radiation and particles (Schwenn, 2006).

1.2 Geomagnetic storms

The emergence of the magnetic field at the photosphere (the lowest part of the solar atmosphere) and its interaction with the solar atmosphere produce both the CME and the flare (see Figure 2). The high speed CMEs develop into interplanetary shocks. When they arrive at Earth, and if they have an IMF negative component ($-B_z$), produce a geomagnetic storm. Also high speed winds produce geomagnetic storm but they are in general less intense than those produced by the CMEs.

The term *geomagnetic storm* must not be confounded with the term *solar storm*. A geomagnetic storm is a prolonged perturbation of the geomagnetic field produced by the impact of the solar activity. They are observed in registers of the time variations of the magnetic field components, these registers are named magnetograms. Usually a geomagnetic storm is accompanied by auroral activity.

CAUSE AND EFFECT IN SOLAR-TERRESTRIAL PHYSICS

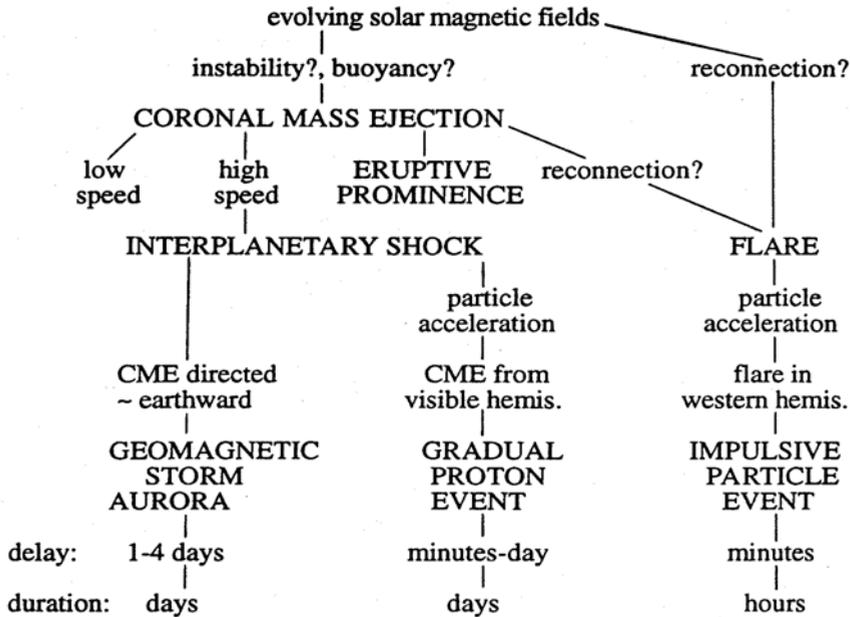


Fig. 2. A scheme relating the solar storm with their impact on the Earth. CMEs and flare (Schwenn, 2006).

A classical geomagnetic storm presents three parts (Tsurutani and Gonzalez, 1997) according to Figure 3.

The first part is a sudden commencement due to the arrival of the shock associated to a high speed CME or to a high speed wind stream. There is a compression of the geomagnetic field. It is observed at low latitude observatories as an increment in the horizontal (H) component of the magnetic field lasting for few hours and presenting variations of several nanoteslas. It is observed in all the planet. Some times there is only the sudden commencement but the rest of the variations in Figure 3 are not present, in this case we only have a sudden impulse. In other occasions, there is no sudden commencement but the other two phases are present. The second part is the main phase. The entry of particles feeds an equatorial ring current that generates a field opposite to that of the planet. It requires the presence of a $-B_z$ component of the IMF. In this way there is a reconnection between the interplanetary and the geomagnetic fields that allows the entry of particles inside the magnetosphere. At low latitudes there is a decreasing of the field that reaches around -100 nanoteslas or less. Lasts several hours up to a day.

The third and final part is the recovery phase. Due to the loss of particles in the ring current, the field increases along few days until it reaches the value it had before the storm.

At the time scales of the 11-years solar cycle, the geomagnetic perturbations are produced by the interplanetary CMEs mainly during solar maximum and the corotating high-speed streams mainly during solar minimum (Tsurutani and Gonzalez, 1997).

Teoloyucan Observatory, México. Magnetic coordinates: co-latitude 70.254, longitude 260.8E. Geographic coordinates: 99° 11' 36" longitude W and 19° 44' 45" latitude N

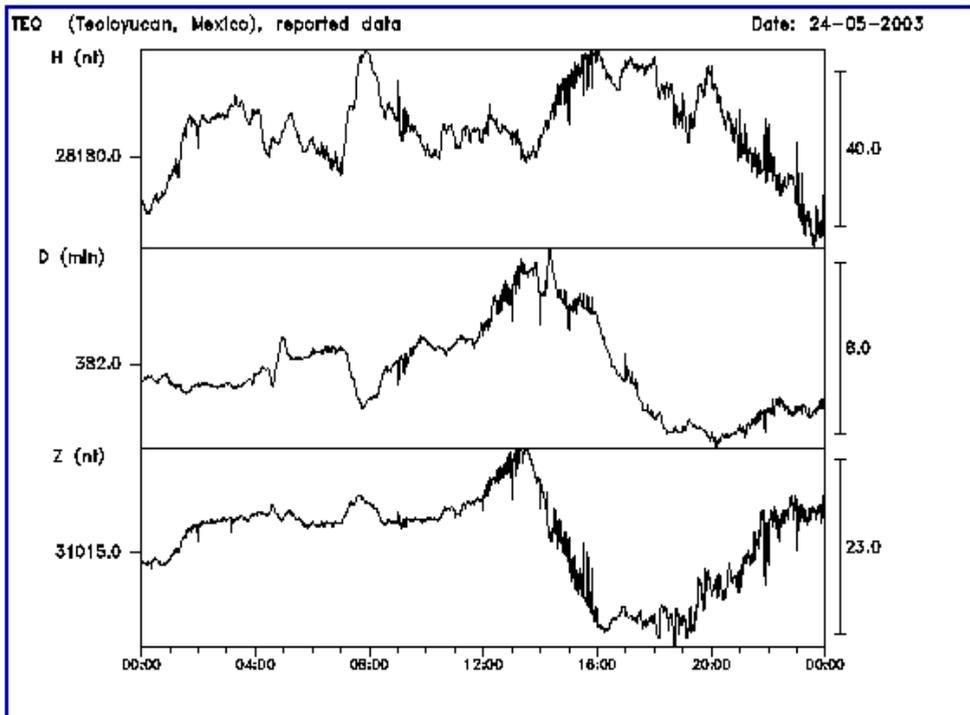


Fig. 3. Magnetogram showing the geomagnetic storm of the 24 of May, 2003 recorded in the Mexican station of Teoloyucan (<http://geomaglinux.geofisica.unam.mx>).

1.3 Geomagnetic indices

They measure the intensity of the geomagnetic activity. Three indices commonly used are the K_p , AE and Dst. The K index is obtained from the H component of the magnetic field, that usually it is the most disturbed; it is defined for intervals of 3hrs. The K_p or planetary index is probably the most used. It is constructed with the average K indices of 12 observatories located between the magnetic latitudes of 48° to 63°. The Dst index or ring current index is the most used to study the magnetic perturbations at low latitudes and measures the intensity of the ring current. The high latitude AE index measures the activity of the auroral electrojet (Campbell, 1997). In Figure 4 we present the distribution of some of the observatories contributing to the construction of the geomagnetic indices.

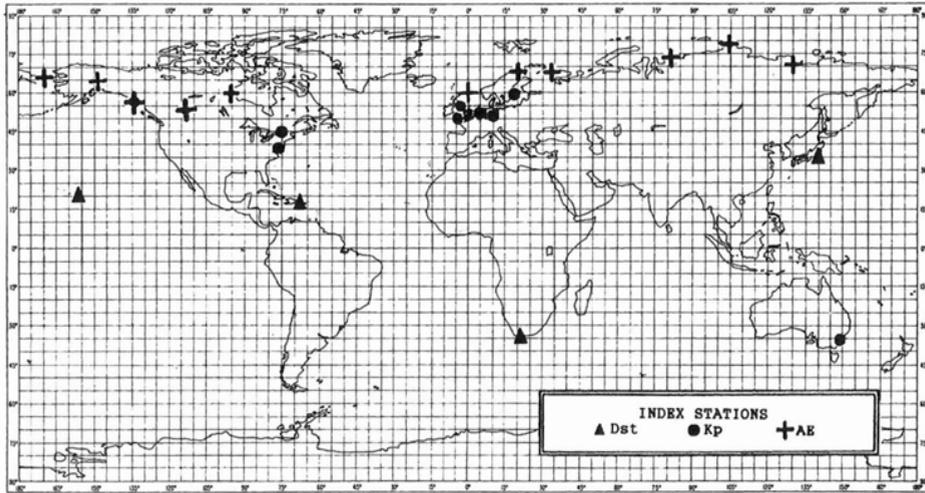


Fig. 4. Global map showing the location of some of the observatories contributing to the formation of geomagnetic indices (Campbell, 1997).

1.4 The concept of space weather

The effect of solar activity on the Earth's environment not only affects the natural phenomena on Earth but also the man-made technology, impacting profoundly the globalized society that exists today. Now it is necessary to forecast the solar activity to quantify the geophysical reaction of the magnetosphere, the atmosphere and the incidence on technology. This is the science of Space Weather.

2. The impact of the space weather on climate

The relation between meteorological phenomena and space weather has been investigated in many reports for over two hundred years. Moreover, an average global warming of $0.6^{\circ} \pm 0.2^{\circ}\text{C}$ has been measured along the 20th century (e. g. IPCC, 2007). It has been attributed preponderantly if not solely to the anthropogenic influence on climate. The current interest of the role of the Sun in climate change stems from the possibility that solar activity is also contributing to the observed temperature increase.

Two mechanism have been proposed for the space weather-climate relations: variations in the total and ultraviolet (UV) solar radiation, and the solar wind modulation of energetic particles.

2.1 Mechanisms relating solar radiation and climate

Changes in the total solar irradiance produce changes in the energy input into the Earth's atmosphere where weather and climate occur and the biosphere exists. The 1367 W/m^2 of solar irradiance arriving to the Earth's orbit is distributed over the planet, then the average solar radiation at the top of the atmosphere is 1/4 of this: $\sim 342 \text{ W/m}^2$. As the Earth has a planetary albedo of 0.3, the incoming radiation is further reduced to 239 W/m^2 . Also, upon

entering the atmosphere wavelengths shorter than 300 nm are absorbed in the stratosphere and above. It is at shorter wavelengths that the total solar irradiance varies the most. For the last two solar cycles, the portion of the total irradiance that actually arrives at the troposphere presents a change with the solar cycle of $\sim 0.1\%$ (see review by Lean, 2000) that seems too small to have an appreciable effect on surface climate, unless amplifying mechanisms exist.

The solar UV spectral emission range shows a strong change between solar maximum and minimum (between 1 and 100%) (see review by Lean, 2000). It has been proposed as forcing because the UV is absorbed by the stratospheric ozone raising the temperature there. The warming of the lower stratosphere produces stronger winds, and penetration of these winds into the troposphere alters the Hadley circulation modifying the equator-to-pole energy transport and the lower atmosphere temperature (Haigh, 1999; Shindell, et al., 1999). The models show the observed 11-year variation in the stratosphere but the amplitude of the simulated changes is still too small compared to the observations (e.g. Larkin et al., 2000). Even more, Foukal (2002) compared his reconstructed UV solar irradiance with global temperature along 1915-1999, finding a poor correlation of $r = 0.46$. This result suggests that the interaction of UV irradiance and climate could be indirect and/or that an amplifying mechanism is at work.

2.2 Mechanisms relating the solar wind modulation of energetic particles and climate

2.2.1 The CR modulate directly the production of clouds

After finding a good correlation between cloud cover changes and CR along 1983-1994 and adopting the mechanism proposed by Dickinson (1975), Svensmark and Friis-Christensen (1997) suggested a direct CR modulation of clouds on time scales of decades and longer. Air ions produced by CR may act as sites for the nucleation of condensation nuclei, in turn these nuclei may grow into cloud condensation nuclei, this step is enhanced by the particles being charged.

2.2.2 Varying electric fields affect ice cloud processes

At temperatures between -40°C and 0°C liquid water cannot freeze spontaneously but requires a surface on which to start freezing. Only a small portion of atmospheric aerosols are suitable sites. In laboratory experiments it has been observed that large electric fields produce freezing of supercooled water droplets. The precipitation of CR, relativistic electrons and the ionospheric potential distribution in the polar cap, each of these affects the ionosphere-Earth current density and therefore the electric fields. Other work indicates that charged aerosol particles are more effective than neutral aerosol particles as ice nuclei. These processes are collectively known as electrofreezing. The latent heat released during freezing is available for modifying the weather systems and therefore ice clouds (Tinsley, 2000).

At the present time the question of whether CR modulate climate directly through cloud changes is not yet settled. The spectrum of opinions goes from the view that the CR are the main contributor to radiative forcing through clouds (e.g. Svensmark, 2007) or that CR can partially affect cloud formation (e.g. Voiculescu et al., 2006), to consider that they have a negligible effect on climate (e.g. Kristjánsson et al., 2008; Erlykin et al., 2009). However, it is also possible that the correlation between CR and clouds is due to the fact that CR fluxes are a proxy of another phenomenon which may influence climate, the total solar irradiance, that anticorrelates with CR (Lockwood, 2002). Pallé-Bagó and Butler (2000) found that the low cloud cover annual means present a slightly higher anticorrelation with SN compared

to the correlation with CR (although they did not comment on that). Kristjánsson et al. (2002) showed that the anticorrelation of the low cloud cover with the total solar irradiance and SN is higher and more consistent than the correlation with cosmic rays. Yet, due to the well known anticorrelation between CR and SN (e.g. Heber et al., 2006) it is difficult to tell which of the two mechanisms is at work, or what combination of the two.

Even more, it is still uncertain whether these mechanisms take place in the atmosphere and if their effect on clouds are measurable.

3. Examples of recent work relating space weather and hurricanes

In this section we review the related papers appearing in the literature in the last 5 years. This review is not intended to be exhaustive; its aim is just to give an idea of the type of work that is currently being developed. But first we present some basic information concerning hurricanes and several of the first attempts to relate space weather and hurricanes.

3.1 Hurricane main facts and data characteristics

Among the meteorological events, tropical cyclones have attracted much attention, due to the devastating effects that produce when they touch populated areas. Tropical cyclones are large-scale circular flows occurring within the tropics and subtropics (Anthes, 1982). Depending upon the magnitude of the maximum sustained winds, cyclones in the Atlantic and Northeastern Pacific oceans are called Tropical Storms (17-32 m/s) and Hurricanes (exceeding 32 m/s). For hurricanes only, there is the Saffir/Simpson scale classification of speed categories: 1 (33-42 m/s), 2 (43-49 m/s), 3 (50-58 m/s), 4 (59-69 m/s) and 5 (exceeding 69 m/s). Categories 1 and 2 are weak hurricanes and categories 3 to 5 are considered major or intense hurricanes.

Atlantic tropical cyclones occur in the regions that include the North Atlantic Ocean, the Caribbean Sea and the Gulf of Mexico. Hurricanes in the Atlantic Ocean are mainly due to easterly waves forming in West Africa, influenced by local convection and mesoscale systems. Another possible source of Atlantic tropical cyclogenesis is subtropical cyclones, which typically form at the equatorward extreme of a mid-latitude frontal zone (Guishard et al., 2007). Tropical cyclogenesis in the eastern Pacific is associated to moist easterly waves intruding from the Atlantic Ocean and the Inter Tropical Convergence Zone, providing low-level cyclonic vorticity maximum in weak vertical wind shear and deep convection, necessary elements for the development of tropical cyclones (Dickinson and Molinari, 2002; Zhender, 1991).

The dominant factors for hurricane formation are the magnitude of the local vertical wind shears (V_z) and the sea surface temperature (SST). The favorable conditions for the development of hurricanes are $V_z < \sim 8 \text{ ms}^{-1}$ and $\text{SST} \sim 27^\circ\text{C}$ or more (e.g. Goldenberg et al., 2001).

Atlantic hurricane information is available since 1851, while Northeast Pacific hurricane data is available since 1949. The hurricane data can be obtained from the National Weather Service via the NOAAPORT satellite data service (<http://weather.unisys.com/hurricane/>). Data before 1944 is not very reliable. Without aircraft reconnaissance and satellite imagery beginning in 1944, some tropical cyclones were either not counted or were miss-assigned as to their correct intensity. It is after the mid 1960's that continuous satellite coverage started. However, reliable data coverage for hurricanes that have affected the United States is available since 1899 (e.g. Landsea, 1993).

3.2 First attempts to relate space weather and hurricanes

Since the 19 century, there have been numerous attempts to link hurricane numbers and tracks to space weather. Some of the most representative ones have been the following: In 1872 Meldrum found a correlation between Indian cyclones and the SN. In 1873 Poey found the same relation for Caribbean cyclones. However after 1910, as Figure 5 indicates, the correlation became an anticorrelation (see review by Hoyt and Schatten, 1997).

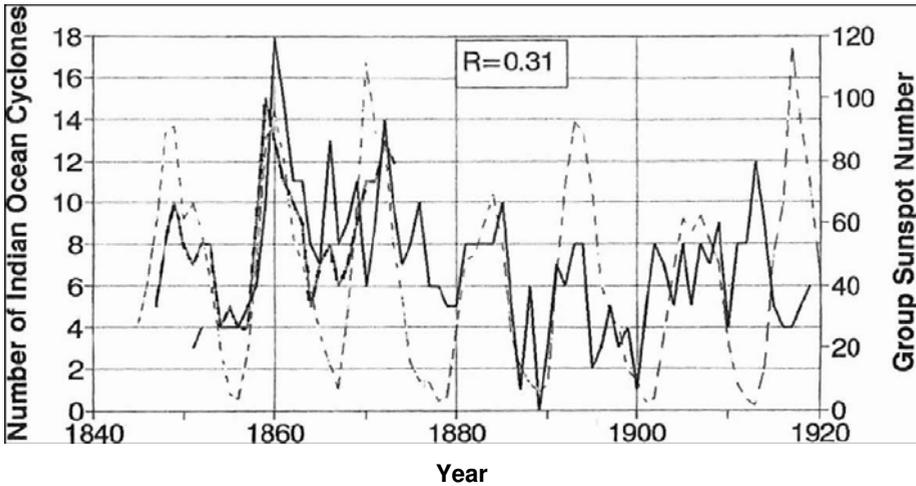


Fig. 5. The number of Indian Ocean cyclones obtained by Meldrum (continuous line with dashes) and Visher (updating Meldrum’s work in 1924, continuous line), and the Group Sunspot Number (dashed line) (Hoyt and Schatten, 1997).

Moreover, Wilcox et al., (1973) found that crossings of the IMF sector were strongly associated to decreases of the vorticity area index as shown in Figure 6. Cohen and Sweetser (1975) found confident periodicities of ~11, 22 and 52 years in the number of Atlantic hurricanes, that coincide with those of the solar cycles. Brown and John (1979) examined storm tracks over the North Atlantic and Europe and found an anticorrelation with the SN cycle.

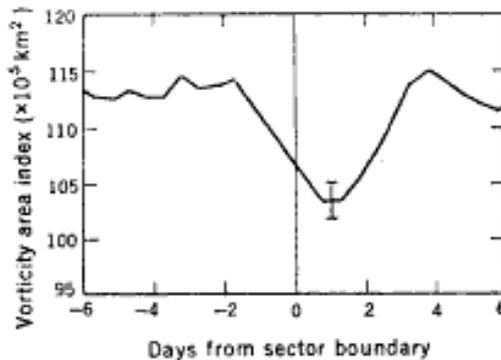


Fig. 6. The decrease of the vorticity area index after the crossing of the IMF sector (day 0) (Wilcox et al., 1973).

3.3 Examples of current work relating space weather and hurricanes

The SN, being the longest direct series of the solar activity has been used profusely in this type of associations. Recently, an inverse relationship between hurricane activity over the Caribbean and the Gulf of Mexico and the SN using a time series between 1866 and 2006, has been reported after considering also the North Atlantic Oscillation (NAO), the Southern Oscillation Index (SOI) and the SST (Elsner and Jagger, 2008). Extending this finding to changes in UV radiation, that presents a rough correlation with SN, a statistically significant anticorrelation was also identified, after accounting for annual SST variation and the El Nino cycle (Elsner et al, 2010). A previous work also suggested that peaks and trends of major north Atlantic hurricane activity concur with lower total solar irradiance, i.e. lower solar activity, and vice versa, in several period between 1730 and 2005 (Nyberg et al., 2007).

Some papers include besides the SN other solar activity-associated phenomena. For instance, correlations between hurricane occurrence, using the available Northeastern Pacific and Atlantic complete hurricane series, and the total solar irradiance, CR and the Dst index of geomagnetic activity have been obtained (Mendoza and Pazos, 2009). The results indicate that the highest significant correlations occur between the Atlantic and Pacific hurricanes and the Dst index (see Figure 7). Most importantly, both oceans present the highest hurricane-Dst relations during the ascending part of odd solar cycles and the descending phase of even solar cycles (Type 2). Conversely, for the ascending parts of even cycles and descending parts of odd cycles (Type 1) the relations are low. This shows the existence of a 22yrs cycle. The cause of such behaviour can be explained as follows: the aa index is $\sim 20\%$ higher during the descending phase of even cycles and ascending phase of odd cycles. These epochs present enhanced transients such as CMEs during the ascending phase of odd cycles, and enhanced high-speed corotating streams, i.e. stronger poloidal fields, during the descending part of even cycles (Cliver et al., 1996). Furthermore, Mendoza and Pazos (2009) found that the Atlantic hurricanes anticorrelate with the Dst index while Pacific hurricanes correlate for Type 2 epochs and they correlate for Type 1 epochs in both oceans. The authors suggest that this behaviour could be due to differences in cyclogenesis and to the presence of large scale climatic phenomena such as the NAO, SOI, etc.

Another work used data for all hurricanes born over the Atlantic and Pacific waters in the last 55 years that hit the Mexican borders (Pérez-Peraza et al., 2008a). The author considered as basic hurricane parameters the maximum rotational velocity and the estimated total energy. The behaviour of the CR intensity, the SN, and the geomagnetic indices Ap and Kp 35 days prior and 20 days after the cyclone start were investigated. The CR, SN, Ap and Kp showed much more intensive disturbances in the periods preceding and following the hurricane appearance.

A statistically positive correlation was found between geomagnetic activity and tropical cyclone intensification over the tropical Atlantic where major hurricanes form. The result is consistent with an earlier study showing a connection between geomagnetic activity and tropical cyclone intensity. It expands on this earlier work by focusing on intensification rather than intensity and by examining hourly data. No significant relationship was found with Forbush decreases (Kavlaikov et al., 2008).

The correlation between variations in geomagnetic activity and tropical cyclogenesis during the complete solar activity cycle 23 was studied. The correlations were calculated for four cyclogenesis regions: the Atlantic, northeastern and central Pacific, northwestern Pacific, and water areas of oceans and seas in the Southern Hemisphere. Such coefficients changed

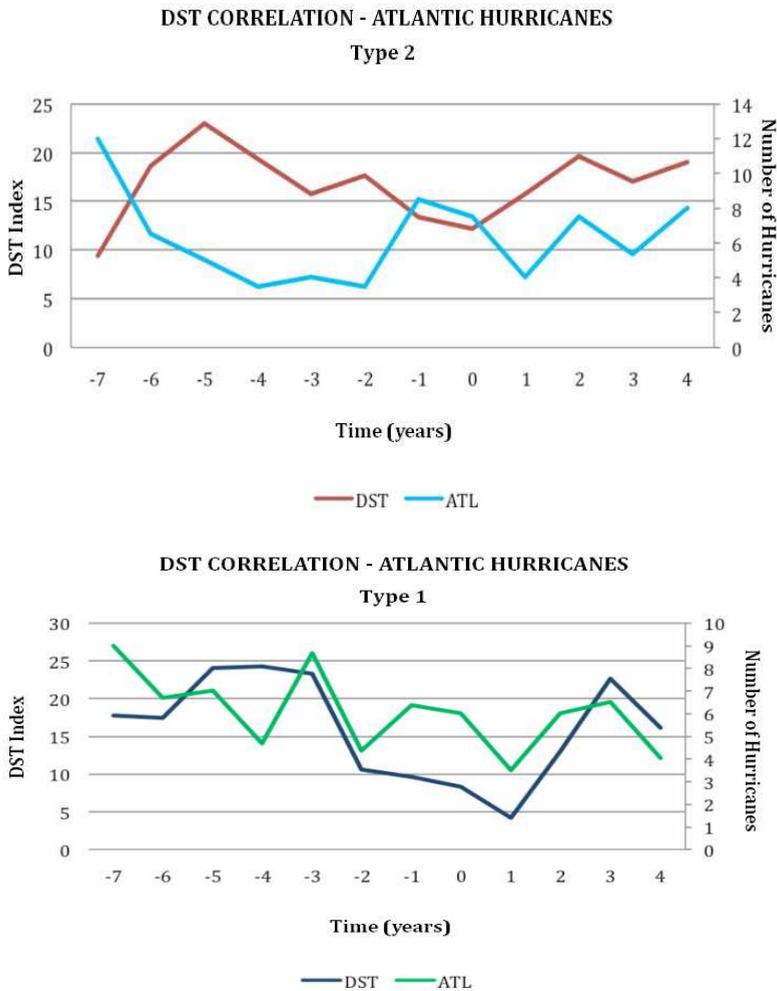


Fig. 7. Superpose epoch analysis for the Dst geomagnetic index and mayor Atlantic hurricanes (1851-2007). The figure shows the difference during Type 1 and Type 2 epochs of the solar activity cycle (Mendoza and Pazos, 2009).

in different regions from positive to negative values and some of them were significant: 0.55, 0, -0.50, and -0.50, respectively (Ivanov, 2007).

IMF crossing are again found to be associated with hurricanes: The generation of the Katrina hurricane was associated to the geomagnetic extrastorm of August 24, 2005, at a repeated crossings of the strongly disturbed IMF sector boundary (see Figure 8). Also few hours after the IMF crossing and before the generation of the hurricane, the flux of 1MeV protons increased. High values of A_p were also observed during the hurricane generation (Ivanov, 2006).

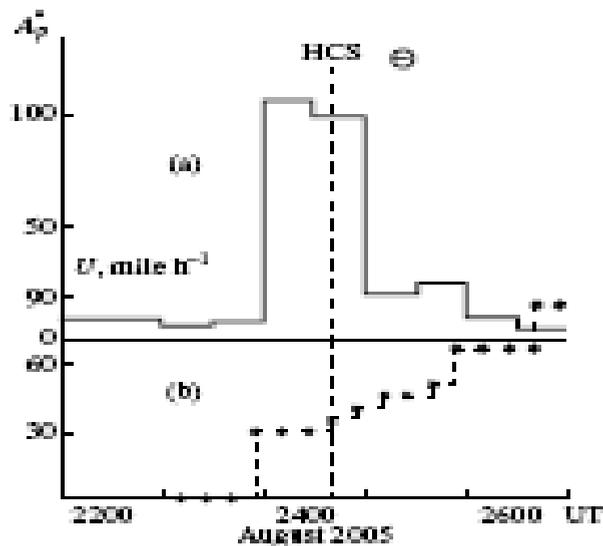


Fig. 8. (a) Variations in the average diurnal A_p values of the a_p planetary index. (b) wind velocity variations during the generation of the hurricane Katrina: depression (dots), storm (crosses) and hurricane (circles). The dashed line (heliospheric current sheet, HCS) marks the instant of the last repeated crossing of the sector boundary and entry into the negative IMF sector (Ivanov, 2006).

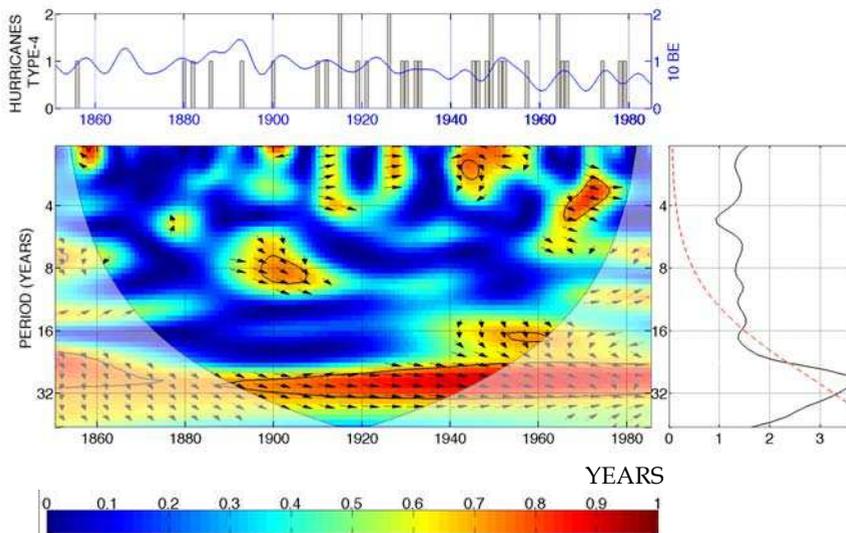


Fig. 9. Wavelet coherence between hurricanes magnitude 4 and CR. Upper panel: time series. Lower left panel: wavelet coherence spectra. Lower right panel: global coherence spectra, the dashed line is the red noise level; a 30 years peak is clearly above the noise. The color bar at the bottom indicates the significance level (Pérez-Peraza et al., 2008b).

Concerning periodicities, a common frequency of 30 years (see Figure 9) was found in the number of tropical storms landing in Mexico, in their average rotational wind velocity and in their total cyclone energy (Pérez-Peraza et al., 2008a). Also from a coherence wavelet study, a common frequency of 30 years was identified between phenomena presumably associated to hurricanes, such as the Atlantic Multidecadal Oscillation (AMO) and the SST versus CR, and on the other hand CR versus Atlantic hurricanes (Pérez-Peraza et al., 2008b). Also applying spectral analysis to the available Atlantic and Pacific hurricane time series, periodicities that coincide with the main SN and magnetic solar cycles were identified: ~11 and 22 years (Mendoza and Pazos, 2009). Another work indicates that Atlantic hurricane activity shows coincidences with several solar cycles (Kane, 2006).

4. Discussion and conclusions

Here we present the comparison of some results, the discussion concerning some proposed mechanism and a general conclusion about the review.

4.1 Comparing results

For the long-time series of the Atlantic hurricanes, SN and UV radiation anticorrelate. Also, other solar activity-related phenomena such as CR, SN, and various geomagnetic indices show large perturbations before and after Atlantic and Pacific hurricanes (Pérez-Peraza et al., 2008a). However, work by Mendoza and Pazos (2009) and Ivanov (2007) have pointed out that the correlations between Atlantic and Pacific hurricanes and solar activity-related phenomena are different. Moreover, Mendoza and Pazos (2009) have also shown that these relations change according to the phase of the solar cycle when divided in the ascending part of odd solar cycles and the descending phase of even solar cycle (Type 2), and the ascending parts of even cycles and descending parts of odd cycles (Type 1).

Mendoza and Pazos (2009) found that the Atlantic hurricanes anticorrelate with the Dst index while Pacific hurricanes correlate. While Ivanov (2007) found that Atlantic hurricanes correlate and northeastern and central Pacific hurricanes have no correlation. We point out that Ivanov (2007) worked only with the odd solar cycle 23, then according to the results of Mendoza and Pazos (2009) during the ascending phase of this cycle a good anticorrelation is expected and oppositely for the descending phase, then the results for the whole cycle cannot be compared with those of Mendoza and Pazos (2009). Moreover, Ivanov (2007) found that the hurricane Katrina, that occurred during the descending phase of odd cycle 23 (in 2005) was intensified after multiple crossings of the IMF sector and in the presence of high geomagnetic activity, as it should have been a low link between Katrina and the Ap index, it is likely that the IMF sector crossing was more important concerning the intensification of the hurricane.

Hurricanes show periodicities that coincide with the 11, 22 and 30 years solar cycles. The 11 years can be clearly associated to the evolution of the SN and other solar phenomena; the 30 years cycle could be a harmonic of the SN Gleissberg cycle (80-90 years). However the association to the 22 years is more complicated, as several possibilities exist. The 22yrs cycle has been identified in solar and geomagnetic activity. The polarity changes of the general solar magnetic field shows this cycle. In SN this periodicity appears in spectral analysis, it is attributed to the low-high alternation of even-odd sunspot maxima. This alternation is

ultimately linked to the solar magnetic field and its changing polarity via the interaction with a relic constant magnetic field in the convection zone (e.g. Mursula et al., 2001; Prestes et al., 2006; Demetrescu and Dobrica, 2007). In CR the 22yrs cycle is associated to the inversion of the Sun's general magnetic field around the maximum of activity (Kota and Jokipii, 1983). The aa geomagnetic index seems to present this periodicity (e.g. Cliver et al., 1996; Demetrescu and Dobrica, 2007), associated to a polarity reversal/geometrical coupling mechanism (Rosenberg and Coleman, 1969; Russell and McPherron, 1973) plus an intrinsic variation of the polar magnetic field of the Sun (Cliver et al., 1996). Climatic phenomena also present a 22 yrs cycle, for instance droughts (e.g. Cook et al., 1997; Mendoza et al., 2005; Mendoza et al., 2006), Russian tree ring width (Raspopov et al., 2004), temperature records (e.g. Dobrica et al., 2008), tree ring width from Brazil and Chile (Rigozo et al., 2007), or total annual rainfall series in southern Brazil (Souza-Echer et al., 2008). Moreover, large-scale climatic phenomena such as the NAO, the AMO, the Pacific Decadal Oscillation or the Southern Oscillation, show quasi-bidecadal periodicities (e.g. Velasco and Mendoza, 2008). Comparing cyclonic activity at middle and subpolar latitudes, the North Atlantic cyclones also show a relation with solar activity: Long-period variations in the cyclonic activity along 1874–1995 indicate oscillations of the surface pressure with periods close to the main periods of solar activity (~80 and ~11 years) (Veretenenko et al., 2007).

4.2 Mechanisms

At present there are two main solar-related proposed mechanisms to account for the relation space weather-climate: The solar and UV radiation, and the solar-modulated energetic particles. For the specific case of the space weather-hurricanes these two proposals also apply:

4.2.1 The total and UV solar radiation

A hurricane's maximum potential energy is inversely related to the temperature at the top of the convective clouds in the central core (Emanuel, 1991; Holland, 1997). An active Sun warms the lower stratosphere and upper troposphere through ozone absorption of additional UV radiation. A warming response in the upper troposphere to increased solar UV forcing decreases the atmosphere convective available potential energy leading to a weaker cyclone (Elsner and Jagger, 2008). General circulation models suggest a mechanism that impacts the baric atmospheric properties; the models show that changes in the stratosphere, induced by interactions between UV and ozone may penetrate down to the troposphere affecting winds and sea level pressure (Shindell et al., 2001); during solar maximum the increased solar radiation increases sea level pressure, which would result in weaker easterly winds and therefore weaker vertical wind shear promoting more hurricanes (Nyberg et al., 2007). In this context, the good relations found between hurricanes and SN would be due to the close relation between SN and solar radiation.

4.2.2 The solar wind-modulated energetic particles

a) There is a possible triggering mechanism for condensation and freezing within the convective clouds of the cyclone (see review by Tinsley, 2000): the ionization of the upper extent of the storm vortex leads to additional latent heat release and subsequent warming of

the core region of the cyclone. Central core-warming is associated with lowering of the surface pressure and thus with intensification of the cyclone (Kavlakov et al., 2008). This ionization can be due to the precipitation of particles coming from either solar and cosmic rays, or to the precipitation of energetic electrons or protons (of MeV energies) from the radiation belts towards the atmosphere; the latter precipitation is associated to the IMF sector crossings (i.e. Wilcox, 1979; Tinsley, 2000; Ivanov, 2006). b) Through changes in the atmospheric transparency impacting on the baric atmospheric properties, caused by variations of the stratospheric chemical composition produced by energetic protons (solar or galactic). These particles may ionize and dissociate nitrogen molecules and produce nitrogen compounds (NO) which in turn determines the concentration of NO₂. The NO₂ intensely absorbs solar radiation in the visible, while the NO exerts a destructive influence on the stratospheric ozone concentration, decreasing the UV absorption in that layer. Then during solar maximum times, more visible and less UV radiation reach the low atmosphere, the inverse happens at solar minimum. The changing amounts of radiation entering the low atmosphere should lead to temperature changes and therefore atmospheric pressure changes that promote cyclonic activity (Pudovkin and Raspopov, 1993).

As mentioned in Section 1, after a solar storm is produced, the energetic particles will arrive to the atmosphere in few minutes-hours. Few days afterwards, the arrival of the CME or the high speed solar wind will cause a Forbush decrease. Then decreases of pressure and then increases will be observed. These baric changes will again modulate the appearance and/or intensification of cyclones.

4.3 General conclusion

As a general conclusion we may say that hurricane activity studied through the number of hurricanes, category, intensification, maximum rotational velocity, total energy, etc., presents a relation with space weather-associated phenomena.

The relations depend on the ocean basin and on the phase of the solar activity cycle. It is likely that various of the proposed mechanisms are at work.

5. Acknowledgements

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This book represents recent research on tropical cyclones and their impact, and a wide range of topics are covered. An updated global climatology is presented, including the global occurrence of tropical cyclones and the terrestrial factors that may contribute to the variability and long-term trends in their occurrence. Research also examines long term trends in tropical cyclone occurrences and intensity as related to solar activity, while other research discusses the impact climate change may have on these storms. The dynamics and structure of tropical cyclones are studied, with traditional diagnostics employed to examine these as well as more modern approaches in examining their thermodynamics. The book aptly demonstrates how new research into short-range forecasting of tropical cyclone tracks and intensities using satellite information has led to significant improvements. In looking at societal and ecological risks, and damage assessment, authors investigate the use of technology for anticipating, and later evaluating, the amount of damage that is done to human society, watersheds, and forests by land-falling storms. The economic and ecological vulnerability of coastal regions are also studied and are supported by case studies which examine the potential hazards related to the evacuation of populated areas, including medical facilities. These studies provide decision makers with a potential basis for developing improved evacuation techniques.

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