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Influence of Cosmophysical Phenomena and African Dust on Hurricanes Genesis

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1. Introduction

The links between the Space Weather and Meteorological Weather have been often discussed not only for the last century ((70) ; (72)), but also for several centuries ago ((99)), and even before some thousands of years ago ((74)). Correlational works between solar and climatic parameters give often interesting results ((4)). A great deal of efforts have been done to clarify the mechanism of all complicated interconnections between the cosmophysical and climatic phenomena at earth, some of them recently summarized by (1), (41), (32) and (23). In the last years more and more investigations show that the solar activity have noticeable impact on the meteorological parameters ((75), (29); (50), (51); (60); (113), (115); (114) and cosmic rays ((67); (52); (24); (13); (71), (95), (94), (130)). Besides some indications appeared that several purely meteorological processes in the terrestrial atmosphere are connected with the changes in the Cosmic Ray (CR) intensity, and influenced by solar activity, and magnetosphere variations ((53), (67), (50)).

One of the main goals of Space climate research is to know how and when the periodicities of space phenomena do modulate terrestrial Climatic changes. Some insights have been obtained: for one side, the solar Hale cycle ($20-25$ years): changes in solar activity for the last 300 years have been studied ((98)), with the aim of revealing a possible contribution of solar activity to climatic variability. On the other hand, quasiperiodic climatic oscillations with periods of $20-25$ years have been revealed in the analysis of parameters such as ground surface temperatures, drought rhythm, variations in sea surface temperature, precipitation periodicity, etc. ((78); (8); (92); (93); (128); (100); (97), (48)). To understand the involved physical mechanisms it is required, as a first step, of confident observational or experimental facts. Nevertheless, to clarify the mechanism of all the complicated interconnections between the cosmophysical phenomena and climatic phenomena at earth, a great deal of efforts have been done; for instance ((23), (32), (1) and (41)).

One of the principal difficulties in quantifying the role of the space phenomena on climate changes has been the absence of long-term measurements of both, the climatic and space phenomena. Consequently, people often recur to the use of proxies. In the last years more and more investigations show that the solar activity ((115), (50)) and Cosmic Rays, have noticeable impact on the meteorological parameters. However, the influence of cosmophysical phenomena on climatic phenomena is currently debated (e.g. (31), (104)). Previous work by means of a correlational analysis ((17); (44), (45); (80)), seems to indicate that certain extraterrestrial phenomena could have some kind of relation with the occurrence of Hurricanes. It is even speculated that such kind of correlations could seat the basis of deeper studies to use the results as indicators of hurricanes precursors. To give to those results a higher meaning, it is convenient to carry out spectral studies of the different involved times series to delimitate with more preciseness the existence of those potential relationships. That is, to find incident cosmophysical periodicities that may modulate terrestrial phenomena. Though the Atlantic Multidecadal Oscillation (AMO) has been linked with the frequency of Atlantic hurricanes, however, in the present context, little attention has been given to such a large scale climatic phenomena: as the question about the role of the Sun in modulating these phenomena has not been clarified, it requires further assessment.

So, special mention must to be done regarding the Links between Geo-external forcing and Hurricanes: correlational works between cosmophysical and climatic parameters may be done, giving often interesting results (e.g. (4)). Within this context, in a series of works ((17); (44),(45); (80),(81)) several efforts were addressed to find possible interconnections between the appearance and development of Atlantic hurricanes and changes in solar activity, geomagnetic disturbances and Cosmic Ray intensity. Changes in geomagnetic activity and sharp Cosmic Rays (CR) decreases, namely Forbush Events (FE), are well known to be related to Solar Activity changes (SS index). These facts provoked the interest of the previously mentioned authors for a detailed study of such collateral phenomena and their statistical comparison with hurricane phenomena. Within that context they were looking for signatures of coadjutant hurricane forecasting to conventional meteorological models, well before the period at which those models usually produce their predictions: it had been analyzed the behavior of the (CR) intensity, Sunspots (SS) and geomagnetic indexes (AP) and (KP) in long intervals preceding the development of the North Atlantic Cyclones, that means, before the first observations of the just born cyclonical system. The authors tried to examine the eventual connection of CR, SS, AP and KP changes with the processes developing in the atmosphere, far before the formation of North Atlantic hurricanes.

Their main hypothesis is that any specific changes of the collateral parameters during the days, preceding the cyclone appearance could be used as an indicative precursor for an approaching hurricane event. In order to reveal any possibility for immediate (not delayed) relationship between them, it was used simultaneous data to find statistical dependencies between the specific sharp changes in the geomagnetic field and cosmic rays intensity and the corresponding values of the hurricane intensification. Their efforts were especially concentrated not only in North Atlantic hurricanes, but in particular those which struck the East Coast of Mexico. All such hurricanes, recorded in the period 1950 − 2007 were analyzed. Trying to generalize the big amount of information obtained from this kind of analysis, it can be said that CR, SS, AP and KP showed much more intensive disturbances in the periods preceding and following the hurricane appearance. For SS this disturbance gradually increase with the hurricane strength. A characteristic peak in the CR intensity appears before the hurricane start. But its place varies between 5 and 20 days before that start. Specific changes were observed in the SS. For major hurricanes they begin sometimes more than 20 days in advance. The AP and the KP show series of bursts, spread over the whole period of 35 preceding days. The chosen long preceding period of days permits to reveal the behavior of these parameters long before the cyclone appearance. Specific precursors exist persistently before the cyclone start.

During the time of major cyclone development specific changes are also noticeable: a considerable change in the solar activity and the depending on it, CR intensity and Geomagnetic field activities, precede the appearance of intense cyclones, though the preceding time fluctuates considerably from event to event. For instance, investigating the daily intensification of KATRINA it has been noticed that a strong geomagnetic change (through changes in KP and AP indexes), was recorded 5 days before its maximum value. From the other side, some repeatedly observed coincidences between the Hurricane appearances and preceding Forbush Effects (FE) (as for example Hurricane ABBY 1960 and CELIA 1970 suggested a possibility for closer relationship between the FE and hurricane intensification. The obtained interconnections show that these parameters should be taken in consideration, when complicated processes in the upper atmosphere are used to determine the hurricane formation, that potentially will contribute to hurricane development forecasts.

Obviously the parameters SS, CR, AP, KP are not the basic driving factor for hurricane appearance and development. At present, it cannot be claimed an accurate forecast of cyclone activity only on the basis of preceding KP and CR, Forbush Effects data drastic changes, However, the results confirmed the preliminary hypothesis suggestion that there is some kind of interconnection between these parameters and the appearance of tropical cyclones - especially with the most powerful of them: Though, it is not pretended by the moment to forecast the creation of a dangerous vortex on the basis of peculiar behavior preceding of those data changes, however, looking at the presented results it could be strongly alerted if a package of large SS and a sharp rise in KP index is recorded together with Forbush decreases appearing during the summer (i.e. trend of the deeper minimum in CR intensity and the higher maximum in SS, for higher hurricane categories). Then investigating all the parallel atmospheric data we could be closer to a most probable prediction.

Finally, it should be emphasized that the results described in those works are limited to a correlational analysis. Though, very interesting results were obtained, however, it should be reminded that that kind of analysis, is only the necessary first step to be done when it is to be determined whether or not there is connection between two time series characterizing to different physical; in fact, correlational analysis only provides global information about the degree of linear dependence between two time series but does not gives information when the correlation dependence is of non-linear nature. Even if the global correlation coefficient is low, that does not means that there is no a physical relation. In fact, there is the possibility that such a relation could be of non-linear nature, or that there is a strong phase shift between the cosmophysical phenomenon and the plausible associated terrestrial effect, or, there is a time delay between one series time (input) and the system reaction (output).

Nevertheless, the obtained results are enough exciting for motivating us to jump to a next step, that is, to reinforce such analysis with collateral methods, by means of a more precise statistical analysis technique, namely the Wavelet analysis (Section 7) which furnishes not only global but also local information in time and frequency band ((35); (116), (117)), that is, it provides the coherence between two series, by means of the evolution of the relative phase between both series, determining whether their correlation is linear or not in different band widths. It may occur that the global correlation coefficient is low, but in some periods of the studied time interval the coherence be, however relatively high, indicating a non-linear correlation (a complex one) in those periods The important feature of wavelet spectral analysis is that it gives the evolution of the synchronization in time-frequency space. In contrast the so called Pearson correlation coefficient does not provides the evolution of the common synchronized periodicities, nor the evolution of the relative phase between two time series.

2. Atlantic hurricanes

Hurricanes are considered one of the most astonishing meteorological phenomena in our planet. Strong winds, clouds of great size and intense storms unite to advance for the ocean and to reach mainland, razing with everything to their passage, fallen trees, damages in buildings, changes in the natural landscape and, fatal victims, are alone some of the consequences that these unpredictable events can generate. Due to the great intensity that they reach, with winds that can overcome the 350 km/hr, they are classified as true natural disasters: whole towns disappear under the force of the impetuous winds. No device achieves, nowadays, to counteract its force; the man has become a simple spectator. Hurricanes have always been associated with the damage that causes mainly translated in human and material losses, but it is necessary to stand out that they also brings such benefits as the increase in precipitation in regions where the agricultural development depends on the precipitation, as well as the recharge of the dams and the bodies of water, vital for the development of the populations. The word hurricane has its origin in indigenous religions of the old civilizations. The Mayan named to their god of the storm as Hunraken. Taino people, a culture of the Caribbean, called Hurricane to a God that they considered malicious. Nowadays, hurricanes are not considered wicked forces but due to their great force, and great potential for loss of lives and material damages, they are considered one of the most powerful phenomena in the nature.

The tropical hurricanes are the only natural disasters to which are assigned a name. These names are known well before they happen and as well as their possible effects, contrary to other natural phenomena as the earthquakes, tornados and floods. Gilberto, Katrina, Mich and Isidoro, to name some of the most recent, are examples that remember a very particular image, for the severe damages that caused. These phenomena present common characteristics, although each one shows particular features. The destruction caused by the hurricanes in the Caribbean and Center America is a force that has modified the history and that it will follow it making in the future in these regions. The danger is born from a combination of factors that characterize to the tropical cyclonal storms: elevation of the level of the sea, violent winds, and strong precipitation. For their location, an example on this, is the Peninsula of Yucatan which is affected in a direct or indirect way by most of the hurricanes that are formed in the Western Caribbean. The hurricanes can have a diameter as long as the peninsula itself, so that practically any hurricane that is formed affects in more or smaller measure the oriental coast of the peninsula ((129)).

To give an idea of hurricanes power, the energy concentrated in the vortex system is estimated to be $> 10^{16} J$ if we consider that the air over a surface with a diameter of $\sim 800 km$ has a mass of $\sim 2x10^{12}$ tons, turning with average velocity of $\sim$ 15 to 20 ms^{-1}, we could easily calculate an energy of $\sim 1011 KWh$). This corresponds to the energy released during the explosion of more than 2000 Atomic bombs of the Hiroshima type. That explains the devastating effect of the hurricanes when it touches a populated area. North Atlantic hurricanes frequently strike the Caribbean islands, Mexico, and the United States. Only one hurricane hitting over their coasts could take hundred human lives and can cause damages for billions dollars and practically every year one or two such hurricanes devastate these regions. They rank at the top of all natural hazards ((16)). The hurricane KATRINA, (Fig. 1), destroying not only the city of New Orleans but vast areas from the states of Louisiana and Alabama is an example of that. The tropical hurricanes are sometimes driven by weak and erratic winds, that makes even more difficult to predict them. Published warnings have substantially improved entailing a decrease of the deaths.

Fig. 1. Hurricane KATRINA, taken from a NASA satellite, it was the deadliest category-5 hurricane to strike the North Atlantic coast

So, today a lot of efforts are devoted to understand better the hurricane formation and intensification to unveil connections with other physical processes, as could be for instance the fact that there has been a low Atlantic hurricane activity in the 1970s and 1980s compared to the past 270 years, but increasing destructiveness over the past 30 years. Also, even if, since the beginning of the 1990 there is a general trend to increase the frequency of tropical cyclones, there are however some years with do not follow such a tendency, as it was the case of 2006. It is hope that the conglomeration of different researches with very different focus contribute, in overall, to the task of improving the prediction of its complicated trajectories for a better foresee of hurricane appearances, prediction of their probable devastation , and then, to warn with enough time the threatened population.

Hurricanes are perturbations that take place in tropical regions where the waters of the ocean are relatively warm (temperatures around the $26 - 27^oC$). They are characterized by a great center of low pressure, around which the air at great speed rotates embracing an extension of several hundred of kilometers. Hurricanes have a certain anatomy and their classification depends on the intensity of the winds, on the atmospheric pressure and on the potential damages that they may cause. Powered by the intensive solar heating, producing fast evaporation in the second semester of each year, large upward hot high velocity circular wind streams are born over the hot equatorial waters of the oceans, with a velocity higher than $60Km/hr$, and reaching rotational velocities beyond $350Km/hr$. Tropical Cyclone is the scientific term for a closed meteorological circulation of enormous mass of atmospheric air rotating intensely, that is developed on tropical waters. These systems to great scale, non frontals and of low pressure happen on areas of the world that are known as tropical basins of hurricanes.

Therefore, the Tropical Cyclone is a low-pressure system that is located over hot waters of tropical oceans (between the tropics of Cancer and Capricorn and at least $4^o - 5^o$ away from equator). The intensive heating, low pressure and resulting powerful evaporation increase fast the rotational wind speed. This huge system moves generally from East to West and slightly to the North, but deviations to the East are not exceptions. These exceptions are dangerous especially for the West coast of Mexico and USA. Generally these cyclones are known under the name of hurricanes. If they are formed over the Atlantic and North-eastern Pacific Oceans.

We use hereafter indifferently the terms cyclone and hurricane. If they are born over the western Pacific Ocean, they are called Typhoons. Because of the earth rotation, they rotate counter clockwise in the North Hemisphere and clockwise in South Hemisphere.

In the first moments of the formation of Tropical Cyclones, when the circulation of the closed isobar reaches a speed of 18 ms^{-1} (i.e. < 34 kt or 61 km/h), the system is denominated as Tropical Depression (TD). This is considered as a tropical hurricane in formative phase. If the sustained speed of the wind ranges from 18 to 32 ms^{-1} (34 till 63 kt, i.e. $62 - 115$ km/h) it is called a Tropical Storm (TS) and a certain name is given. Likewise, when the speed of the wind exceeds the 119 km/h or > 33 ms^{-1} (> 64 kt) the system takes the name of Hurricane (or Typhoons). That is the speed accepted to define the beginning of a hurricane over the Atlantic and a typhoon over the Pacific. They have a defined nucleus of pressure in very low surface that can be inferior to 930 hpa. Every year develops an average of 10 tropical storms in the Ocean Atlantic, the Caribbean or the Gulf of Mexico, and about 6 of those which end up becoming hurricanes. In a three year-old period, the North Atlantic coasts receive an average of five hurricanes, two of those which are considered bigger hurricanes. In general, the tropical depressions and tropical storms are less dangerous than the hurricanes; however, they can still be mortal. The winds of the depressions and tropical storms are not the most dangerous thing.

The intense rains, floods and the severe natural phenomena, as the tornados, are the biggest threat. Hurricanes can then be described as turbulence phenomena caused by a current of hot air that is formed in the summer in the tropic and that it goes to the North Pole compensating the difference in temperature between the Ecuador and the Pole. One counter current of the north to the south, compensates the difference in pressure. This circulation of winds north-south and south-north at level of the north hemisphere, together with the daily circulation of the earth that causes the trade winds, are the main factors from the point of view of the winds to create situations that can form hurricanes. Another condition for the formation of a hurricane is the temperature of the surface of the ocean, as energy source to give form to the phenomenon, which should be $>$ to 26^oC. Under these conditions, it is the column of hot and humid air originated in the ocean the one that becomes the nucleus around which rotate the winds and form later the so called "eye" of the hurricane.

The adjacent air is gradually involved in the rotation and the diameter of the whole vortex spreads to $500 - 1000$ km. With the further increase of the circular velocity, reaching sometimes $150 - 160$ kt (80 ms^{-1}), the whole vortex spread out to a gigantic ring with a diameter of several hundred kilometers. As we said before, in its center there is a relatively calm region called the "Eye" of the hurricane. Around it, the rotational velocity is the greatest and decreases out of the center. With the increase of the circular velocity, the whole vortex spread out to a gigantic ring with a diameter of several hundred kilometers (Table 1). In his East-West motion the whole system sweeps a lane about 1000 km wide. It gradually intensifies its rotational wind velocity, simply cooling the hot oceanic surface (e.g. (47)). Lingering over the ocean sometimes $20 - 30$ days, these systems describe complicated trajectories. The lost of energy of the phenomenon usually happens when the hurricane moves inside coastal areas and it goes into to the continent.

The energy that requires a hurricane to maintain its activity comes from the liberation of heat that takes place in the process of condensation of the vapor of water that it evaporates from the surface of the ocean, forming nebulosity and intense precipitation. When a hurricane enters in the continent it loses intensity quickly when stopping the process of strong evaporation from the surface. The hurricane works like a vapor machine, with hot and humid air providing its fuel. When the sunrays heat the waters of the ocean, the humid air warms; it expands and begins to rise as they make it the globes of hot air. More humid air replaces that air and that same process begins again. The rotation of the earth eventually gives it a circular movement to this system, the one that begins to rotate and to move as a gigantic spinning top. As in all hurricane, this turn is carried out in having felt clockwise in the south hemisphere and counter clockwise in the north hemisphere.

Parameter	Range	Average	Unit
Diameter (D)	$200 - 1300$	500	km
Eye	$6 - 80$	50	km
Rot. velocity (V)		0	$ms^{-}1$
Duration	130	8	$days$
Kinetic Energy	4-8	6	Twh
Surface winds:		> 33	$ms^{-}1$
Energy Source		Latent Heat Release	
Equivalent Energy		2000 Bombs Hiroshima Type	
Lives (North Atlantic)		$200,000$ from year 1700	
Damages (North Atlantic)		1180 billion dollars from year 1900	

Table 1. Basic Hurricane Parameters

All the tropical depressions that grow deriving in hurricanes originate practically under the same conditions, and they conserve the same meteorological characteristics to the long of the life. The physical differences that can be presented from an event to other reside in the speeds that each event can reach and the time that these they can stay.

Recent studies on the formation of hurricanes point out like cause, the violent circulation of air in them and the transformation of the liberated caloric energy when it condenses the vapor of water contained in the air that ascends from the surface in a very extensive area. Such a condition implies having an appropriate provision of latent heat, and of some mechanism that trigger and maintain the upward vertical movement required to produce the condensation of the vapor, and with it the liberation of that latent heat. These requirements are satisfied when the temperature of the seawater in a specific area is as we said before, equal same or higher to $26^{o}C$, when the distance of the same one to any coast or island is superior to 400 km, and when inside that same region, convergence associated to any perturbation exists, be tropical wave, polar water-course, inter-tropical convergence line or area. The conditional instability is an atmospheric state that favors the formation of a hurricane in a potential region; it has been a clear relationship between the presence of the instability and the favorable months for the formation of the tropical hurricanes.

The temperature in the ocean and the high relative humidity in the stocking and low troposphere are also requirements for the development of the hurricane. In Fig. 2 figure shows a map of the superficial temperature of the sea for the summer in the north hemisphere . The yellow, the orange, and the red colors demonstrate the temperatures of the quite hot water to sustain hurricanes. Another necessary condition for the organization of the circulation inside the region in which ascents of air and the liberation of latent heat of vaporization take place, is that they happen in a superior latitude at 5^{o}, since in an inferior latitude the organizing effect of coriolis (rotate of the earth) it has very low values. It is for this reason that the hurricanes are formed and are intensified when they are located on tropical or subtropical oceans in both hemispheres where the force of rotation of the earth is sufficiently strong, so that the rotation movement begins around the center of low pressure and whose temperatures of water at surface level are around 26.5^{o} or warmer. The main development region for tropical cyclones

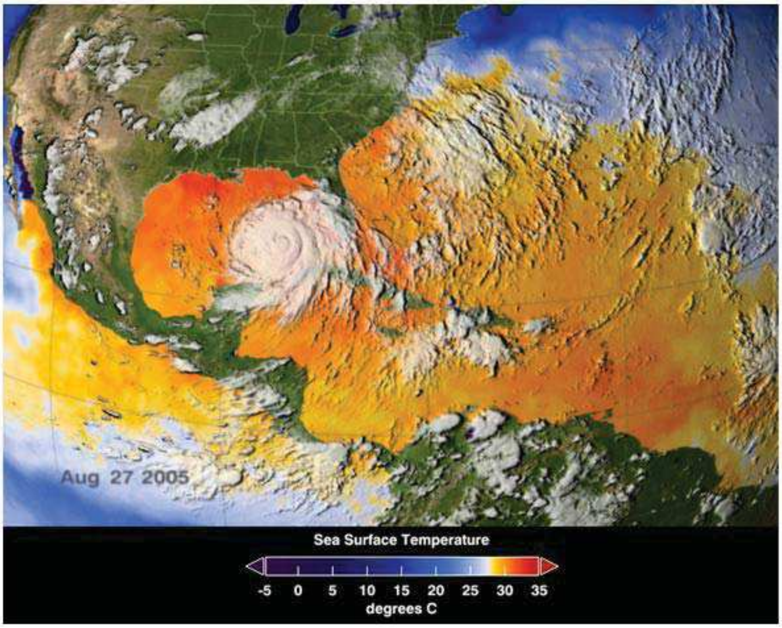

Fig. 2. Hurricane Katrina and the Sea Superficial Temperature

is the basin bounded by 25 and 60 degrees W longitude and by 8 and 23 degrees N latitude where effects of Ocean heat content on hurricane genesis are almost constant (Fig. 3).

Depending on the rotational velocity, which extreme exceeds 165 $knots$ ($> 300\ km/h$), the hurricanes themselves are classified in several ways, generally based upon the vortex wind velocity and their destructive power. In 1969, the Organization of United Nations requested the evaluation of the damages generated by the passage of the hurricanes in a certain type of housings. Starting from it, the North American engineer Herber Saffir and the then director of the National Center of Hurricanes of United States, Robert Simpson, developed a mensuration scale to qualify the potential damages that it can cause a hurricane, considering the minimum pressure, the winds and the tide after its passage. This is now know as the Saffir-Simpson scale and consists of seven categories: Tropical Depression, Tropical Storm and five categories of hurricanes going from hurricanes type-1 up to type-5 (Table 2). Independently of hurricane category, the damages they potentially may cause are more intense when their translation speed is small or almost zero, provided they stay longer time over one location.

According to this scale, hurricanes evolution is as follows:

- Birth (tropical depression): first it is formed a peculiar atmospheric depression because the wind begins to increase in surface with a maximum speed of 62 km/h or less; the clouds begin to be organized and the pressure descends until near the 1000 hectopascales (hpa).
- Development (tropical storm): the tropical depression grows and it acquires the characteristic of tropical storm, what means that the wind continues increasing to a maximum speed of 63 to 117 km/h; the clouds are distributed, in hairspring form and it begins to be formed a small eye, almost always in circulate form, and the pressure decreases to less than 1000 hpa. It is in this phase when it receives a name corresponding to a list formulated by the World Meteorological Organization (Committee of Hurricanes). Formerly, each hurricane

Fig. 3. Control Geographic Basin, where the water surface temperature is practically constant.

Range Storm Knots	Range km/h	Range m/s
TD $30-34$	$56-62$	$15-17$
TS $35-64$	$63-118$	$18-32$
H1 $65-82$	$119-153$	$33-42$
H2 $83-95$	$154-177$	$43-49$
H3 $96-113$	$178-209$	$50-58$
H4 $114-135$	$210-249$	$59-69$
H5 > 135	> 249	> 69

Table 2. Saffir-Simpson scale. MAX Rot. Wind Velocity

was denominated with the name of the saint of the day in that it had been formed or it had been observed. It fits to clarify that if a hurricane causes an important social and economic impact to a country, the name of that hurricane doesn't appear in the list again.

- Maturity (hurricane): the tropical storm is intensified and it acquires the characteristic of Hurricane, that is to say, the wind reaches the maximum of the speed, being able to reach even 370 km/h, and the cloudy area expands obtaining its maximum extension between e 500 and 900 km of diameter, producing intense precipitations. The eye of the hurricane, whose diameter varies from 24 to 40 km, is a calm area free of clouds. The intensity of the hurricane in this stage of maturity graduates by means of the scale of $1-5$ of the Saffir-Simpson scale.
- Dissipation (Final Phase): The pressure in the center of the system begins to increase and the winds fall gradually accompanied by a weakening of the system. In this stage the hurricanes that penetrate to land become extra-tropical hurricanes. A central factor in the end of a hurricane is the lack of energy sustenance provided by the warm waters. Another is that when arriving to earth, the friction with the irregular surface of the land provokes cloudy expansion of the meteor and it causes its detention and dissipation in strong rains. An additional factor is that the hurricane meets with a cold current.

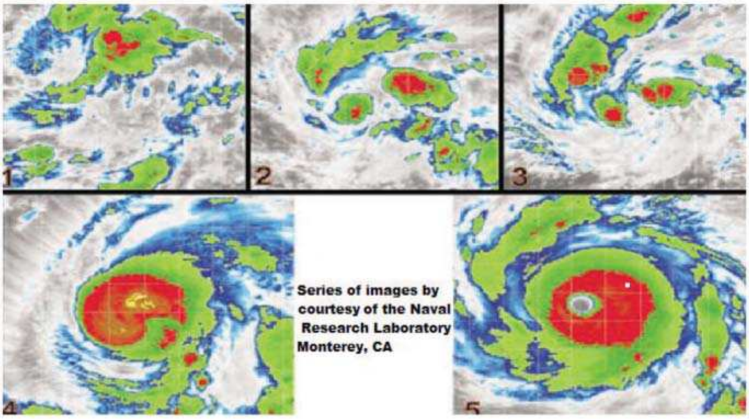

Fig. 4. Series of images of Hurricane Floyd, 1999 (Naval Research Laboratory)

Figure 4 presents some images taken in a period of 6 days, during the stages of development of a hurricane: in photo 1 - we see a good tropical disturbance that favors a tropical depression 12 hours later, in photo 2, we see a tropical depression that continuous with their escalation. In photo 3, the hurricane Floyd has been intensified in a tropical storm. In photo 4 one can already observe to Floyd like a hurricane of category-1 and in photo 5 it is already observed as category-4.

Tropical cyclone intensification depends on many factors ((9)) including oceanic heat content and proximity to land, etc. The hurricanes are formed and are intensified when they are located on tropical or subtropical oceans in both hemispheres where the force of rotation of the earth (Coriolis) it is sufficiently strong so that the rotation movement begins around the center of low pressure and whose temperatures of water at level of the surface are quite warm. The main regions are not stable as for their location, since this obeys the position of the centers of maximum marine heating, those that in turn are influenced by the cold currents of California and the equatorial warm counter current in the Ocean Pacific, as well as for the drift of the ramifications of the warm current of the "Gulf Stream". Also, they do not stay for themselves on land, independently of the superficial temperature.

An analysis of the trajectories of tropical hurricanes shows that there is not coastal area of Mexico that is free of the threat of the tropical depressions that arrive in many cases to the hurricane intensity. In the Gulf of Mexico and in the Pacific the coast of the country is vulnerable to the effects of the tropical storms, although their behavior in both coasts is something different. The depressions that are generated in the southeast of Mexico, specifically in the Bank of Campeche, they generally go toward the north, while those of the Caribbean travel toward the west until touching the costs of Central America, or those of the Peninsula of Yucatan. When they cross it, they vanish, but not enough to be annulled, due to the narrowness of the peninsula, so when arriving to the Gulf of Mexico they find the warm water again that reefed them, recovering their fury and continuing their devastating work.

In a study on the activity of the depressions in the North Atlantic during the first half of last century, some investigators found that more than 78% of those happened in the Gulf of Mexico took place starting from 1932, and only 36% has reached the hurricane force; the duration of these depressions has been of 4.4 days and that of the hurricanes of 2.2 days. The closed form of the Gulf conditions their short duration and low frequency, since the storms reach rapidly the land and then vanish. The Peninsula of Yucatan is the most affected by the depressions and, of the total previously mentioned a 46% affected the peninsula. In the last two decades it has been increased the frequency and intensity of the hurricanes in this region; they should stand out Gilberto in September, 1988 and Mitch in October, 1998.

The season of hurricanes gives principle when the climatic equator moves in direction of the poles carrying with it high temperatures that heat the air and the seawater, giving place this way to the emergence of an area of low pressure. This generally happens between the months of May and November. Summarizing, for a hurricane may be formed there need to be present certain elements:

- Pressure: witnesses or preexistence of a convergence zone in the low levels and low superficial pressure, of synoptic scale.
- Temperature $> 80^o F$: At this temperature, the water of the ocean is evaporating at the required quick level so that the system is formed. It is that evaporation process and the eventual condensation of the vapor of water in form of clouds the one that liberates the energy, that gives the force to the system to generate strong winds and rain. And since in the tropical areas the temperature it is usually high, they constantly originate the following necessary element.
- Humidity: As the hurricane needs the evaporation energy like fuel, there must to be quite a high humidity, which happens with more easiness on the sea, so their advance and increment in energy happen there more easily, weakening when arriving to mainland.
- Wind: The presence of warm wind near the surface of the sea allows there to be a lot of evaporation and that it begins to ascend without big setbacks, originating a negative pressure that crawls to the air in hairspring form toward inside and up, allowing that the evaporation process continues. In the high levels of the atmosphere the winds should be weak so that the structure stays intact and the cycle is not interrupted - Gyre (or Spin): The rotation of the earth gives a circular movement to this system, which begins to rotate and to move as a gigantic spinning top. This turn is carried out in sense contrary to that of the pointers of the clock in the north hemisphere, and in favorable sense in the south hemisphere.

Finally it is worth mentioning that Meteorologists have records of North Atlantic hurricanes that date back into the $19th$ century. Over the last half-century, these records are based on a wide range of measurements including ship and land reports, upper-air balloon soundings, and aircraft reconnaissance. Lately, it was also included radar imaging and satellite photographs. The geographical position of the Eye center and the rotational velocity is measured and published every 12 and lately every $6h$.

3. African dust

Great quantities of dense dust supply from the great North African and Asian deserts are often carried over huge areas of the Caribbean, the tropical North Atlantic, the temperate North Pacific and Indian oceans during much of the year, with different effects in those regions (Fig. 5). The environmental conditions of Earth, including the climate, are determined by physical, chemical, biological, and human interactions that transform and transport materials and energy; this "Earth system" is a highly complex entity characterized by multiple nonlinear responses. One important part of this system is soil dust which is transported from land through the atmosphere to the oceans, affecting ocean biogeochemistry and hence having feedback effects on climate and dust production ((40)).

Dust production arises from saltation and salt blasting, when winds above a threshold velocity transport soil grains horizontally, producing smaller particles, a small proportion of which get

Fig. 5. Dust Plumes off Western Africa,September 15, 2010 (Earth Observatory, NASA)

carried up into the atmosphere for long-range transport processes. These processes depend on rainfall, wind, surface roughness, temperature, topography, and vegetation cover, which are interdependent factors linked to aridity and climate in a highly nonlinear way. Such a production depends on the supply of wind-erodible material, which ironically usually requires fluvial erosion, often from adjacent highlands, followed by subsequent drying out and the loss or absence of vegetative protection. Desert dust aerosol is dominated by particles of diameter 0.1 to $10\mu m$, with the mean size being around $2\mu m$. Such aerosols have a lifetime of hours to weeks, allowing long range transport over scales of thousands of kilometers ((14), (25)) but producing strong gradients of dust deposition and concentrations that vary substantially on time scales of $\sim$ 1day.

Dust winds show large interannual changes that are highly anticorrelated with rainfall in the Soudan-Sahel east African droughty regions. The annual emissions budgets over Sahara (North of 21.25^oN) and Sahel (South of 21.25^oN) in North Africa indicates that from Sahara are twice the corresponding emissions from Sahel, and represents 64% of North Africa and 42% of global emissions. For both regions, the year 1996 has the lowest annual emission. At global scale it is know that dust concentrations were sharply lower during much of the 20th century before 1970, when rainfall was more normal. The interannual variability of African dust transport over the north tropical Atlantic is monitored using in situ surface concentrations measurements performed at Barbados since 1966, along with the Total Ozone Mapping Spectrometer (TOMS) and Meteosat dust optical thickness (DOT) records covering the last two decades.

Much of the transport of dust occurs at altitudes of several kilometers, with subsequent removal by wet deposition. Dust deposition estimates are in the order of $1.7x10^(15)$ gr year^{-1} varying substantially from year to year, with almost two-thirds from North Africa and 26% of the dust reaching the oceans. Dust production, transport, and deposition to the oceans depend on climatic factors, particularly atmospheric structure, which regulates uplift, and wind speed and precipitation, which influence removal. Over large areas of the Earth, the atmospheric aerosol composition is dominated by mineral dust. Dust storms and dust plumes are the most prominent, persistent, and widespread aerosol features. The great variability of African dust transport has broader implications : Iron associated with dust is an important micronutrient for phytoplankton ((21)). Thus, variations in dust transport to the oceans could modulate ocean primary productivity and, consequently, the ocean carbon cycle and atmospheric CO_2. Dust could play a positive role in reducing global warming by greenhouse gas CO_2. Carbon fixation by phytoplankton in the oceans acts as a sink for CO_2. Aeolian dust deposition is the primary source of bio-available iron in the iron-limited open oceans and effectively controls hytoplankton blooming ((68)). Another important effect of dust particles is their role in the photochemical production of tropospheric ozone by reducing by as much as 50% the photolysis rates (e.g. (12); (63); (69)) and by providing reaction sites for ozone and nitrogen molecules (e.g. (84); (11)). Additionally, dust particles affect air quality ((87)) and are potential vectors for long range transport of bacteria.

The great variability in dust transport demonstrates the sensitivity of dust mobilization to changes in regional climate and highlights the need to understand how dust, in turn, might affect climate processes on larger scales: Mineral dust, emitted by wind erosion of arid and semiarid areas of the Earth, is thought to play an important role in climate forcing. However, it has been difficult to quantify because of the relatively complex and highly uncertain effect of dust on radiative forcing ((38); (106)). Because of the great sensitivity of dust emissions to climate, future changes in climate could result in large changes in dust emissions from African and other arid regions that, in turn, could lead to impacts on climate over large areas.

In order to understand the forcing involved in past climate trends and to improve estimates of future dust-related forcing, it is necessary to characterize the variability of dust emissions in response to climate-change scenarios and to distinguish between natural processes and human impacts. Aerosols, including mineral dust, can affect climate directly by scattering and absorbing solar radiation and indirectly by modifying cloud physical and radiative properties and precipitation processes ((42)). Theoretical and experimental studies have shown that the effect of the mineral dust component in the atmospheric radiation budget is comparable to the greenhouse effect gases but opposite in sign. In fact, dust can have either a net positive or negative radiative effect depending on the surface albedo and the aerosol single scattering albedo [Liao and Seinfeld, 1998]. The Saharan Dust Experiment (SHADE) experiment, held off the coast of West Africa during September 2000, shows that the net radiative impact of African dust, if extrapolated to all sources of the entire Earth, would be approximately -0.4 Wm^{-2}. However, because of the complexities of the competing solar and terrestrial radiative forcings, even the sign of the net effect is unknown ((38)), suggesting a dust radiative forcing in the range $+0.4$ to -0.6 Wm^{-2}.

Mineral dust may also exert an indirect radiative effect by modifying cloud properties and precipitation process ((101); (102)). The quantification of the dust impact on climate change is however particularly uncertain because of the lack of knowledge about the natural variability of dust emissions and the temporal and spatial variability of transported dust. Another major uncertainty is due to the lack of reliable estimates of the anthropogenic fraction of mineral dust in the atmosphere ((33)). Recent estimate of this anthropogenic fraction using climate models is of about 10% of the global dust load ((112)).

Several studies have shown that dust particles, by absorbing and scattering solar radiation, modify the atmospheric radiative budget (e.g. (Tegen & Lacis 1996); (105); (124)).

Nonetheless, dense dust clouds over the oceans reduce insolation at the ocean surface, thereby reducing the heating of ocean surface waters ((10)) and sea-surface temperatures, which in turn affects the ocean-atmosphere transfer of water vapor and latent heat, which are important factors in climate ((61)). Reduced heating over the tropical Atlantic could contribute to the interhemispheric, tropical Atlantic, sea-surface temperature anomaly patterns that have been associated with Soudan-Sahel drought ((54); (127)). Thus, increased dust could conceivably lead to more intense or more prolonged drought. Dust could also affect climate through cloud microphysical processes, possibly suppressing rainfall and conceivably leading to the perpetuation and propagation of drought ((101)). Over south Florida, clouds are observed to glaciate at relatively warm temperatures in the presence of African dust ((102)), an effect that could alter cloud radiative processes, precipitation, and cloud lifetimes. Besides, the frequency and intensity of Atlantic hurricanes have been linked to East African rainfall ((55)), showing decreased activity during dry phases. Although there is no evidence that exposure to dust across this region presents a health problem, it does demonstrate how climate processes can bring about changes in our environment that could have a wide range of consequences on intercontinental scales. It is thus important to understand the long-term variability of dust distribution, in order to determine which processes are controlling such variability.

(36) has shown that the circulation and precipitation over Europe and the North Atlantic is modulated by the North Atlantic Oscillation (NAO) with a period of about 8 years.(26) found that in winter a large fraction of the North Atlantic and Africa dust loading is correlated with the North Atlantic Oscillation (NAO) index. They show that a controlling factor of such correlation can be attributed to dust emission from the Sahel. The Bodele depression is the major dust source in winter and its interannual variability is highly correlated with the NAO. Studies based on Meteosat/visible light spectrometer (VIS) and Total Ozone Mapping Spectrometer (TOMS) observations (22 years from 1979 to 2000) have established the link between Sahel drought, dust emissions in Sahel and summer dust export over the Atlantic ((73)), and have shown the role of the North Atlantic Oscillation (NAO) on winter dust transport ((5)).

Dust export to the Atlantic ((73)) and to Barbados ((89)) are most highly correlated with Sahel rainfall of the previous year (i.e., the rainy season preceding the dust occurrence). The significant correlations obtained between interannual variability of summer surface dust concentrations at Barbados, and that of TOMS/DOT over both Sahel and northeastern tropical Atlantic suggest that Sahel sources significantly contribute to the dust transport over the western Atlantic. Thus the Sahelian region, if not of first importance in terms of intensity of dust emissions compared to the Saharan sources ((88)), is probably critical in controlling the year-to-year variability of dust export, which should allow to progress in the understanding of the mechanisms of influence of these climatic parameters, and to provide more accurate estimates of the anthropogenic fraction of mineral dust. In spite of coverage limitations of TOMS and DOT, their agreement among them and with different kinds of ground-based measurements (aerosol optical thickness) (73) and mineral dust concentrations ((6)) gives a picture of dust dynamics with a reasonable confidence level. Finally, it should be emphasized that the frequency and intensity of Atlantic hurricanes have been linked to east African rainfall ((55)), showing decreased activity during dry phases.

4. Relationship between North Atlantic cyclone activity and African dust outbreaks

The recent increase since 1995 in Atlantic tropical cyclones (including both hurricanes and tropical storms) affecting North America has raised the awareness of their impact on society and the economy. Currently, there is a debate surrounding the cause of this observed

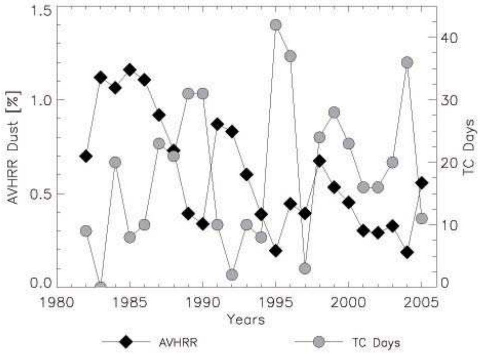

Fig. 6. Time series of North Atlantic tropical cyclone days and Saharan-induced dust cover for 19822005. The black line and diamonds represents the detected dust cover and the gray line and circles represents the tropical cyclone days, over the region of 030*N* and 1560*W* for the time period of August 20 through September 30 ((20)).

increase in cyclone activity. Several recent studies have explored the relationship between long-term trends in tropical cyclone activity (either in terms of their number or intensity) and environmental factors that may or may not be influenced by global warming ((18), (19); (56); (118); (125)). Other studies, however, have concluded that different environmental factors -not necessarily related to global warming- control trends in cyclone activity ((27);(49)).

The role of atmospheric dust as possible contributor to changing North Atlantic tropical cyclone activity was suggested by (15), who showed that tropical cyclone activity may be influenced by the presence of the Saharan Air Layer, which forms, as previously mentioned, when a warm, well-mixed, dry and dusty layer over West Africa is over imposed to the low-level moist air of the tropical North Atlantic ((3), (85)). In fact, historical data indicates that Saharan dust may have a stronger influence than El Niño on hurricane statistics in the subtropical western Atlantic/Caribbean region, while El Niño influence may be stronger in the tropical eastern Atlantic.

It was also mentioned in the previous sections that Atlantic tropical cyclone activity varies strongly over time, and that summertime dust transport over the North Atlantic also varies from year to year, but any connection between tropical cyclone activity and atmospheric dust has been only recently examined. (20) reported a strong relationship between interannual variations in North Atlantic tropical cyclone activity and atmospheric dust cover as measured by satellite, for the years $1982 - 2005$ (Fig. 6).

Due that dust observations are a good proxy for the Saharan Air Layer, ((20)) showed that the contrast between the presence of dust and the lack of tropical cyclone activity for the 1983 and 1985, in particular when dust activity during the 1980*s* was more intense than during any other period in the record; the appearance of cyclone days where dust is lacking in the years 1995 and 2004, suggests an inverse correlation between dust and tropical cyclone activity, what is consistent with the hypothesis of (15). (20) suggest the possibility that the intense activity of the Saharan Air Layer indicates the presence of an environment less conducive to deep convection and tropical cyclogenesis, whereas the lack of Saharan Air Layer activity demonstrates the opposite situation. It can be speculated that the anomalous low Hurricane activity during the decades 1970*s* and 1980 was due to a general high dust activity. In fact, that is true during the 1980*s*.

A correlation coefficient of $\sim$ 0.51 is observed between tropical cyclone and dust activities time series, significant at $\sim$ 99% during the last decade, Goldenberg et al, (2001). Sea surface temperature is important in shaping the interannual variability of North Atlantic tropical cyclones ((27); (57)). However, over at least the last 26 years regional tropical cyclone activity and sea surface temperature exhibit an upward trend, while dust activity shows a downward one. The partial correlation coefficients of the de-trended time series are both -0.50, significant at 98.5%. Implying that Saharan dust activity can account for variance in the tropical cyclone record that cannot be attributed to ocean temperature. The Accumulated Cyclone Energy (ACE) time series for the topical Atlantic is also well correlated with dust cover series, with a correlation coefficient of 0.59, significant at 99.5%, possibly reflecting the effects of the Saharan Air Layer on cyclone intensity as well as genesis, as suggested by (15). ACE index is defined as the sum of the squares of the maximum sustained surface wind speed (knots) measured every six hours for the Hurricane Best Track Files ((39)).

Although the mean dust coverage and tropical cyclone activity are strongly (inversely) correlated over the tropical North Atlantic, this does not provide conclusive evidence that the dust itself is directly controlling tropical cyclone activity. It has been mentioned that a link exists between Sahel precipitation and North Atlantic hurricanes: increases in Sahel precipitation are thought to cause increases in North Atlantic hurricane activity through enhancement of African easterly waves, and reductions in Sahel precipitation and North Atlantic hurricane activity have been tied together through the associated changes in wind shear across the Atlantic basin ((28); (55)).

Therefore, it is possible that if precipitation changes in the Sahel alter West African dust outbreaks, then this variability in rainfall may be the cause of our observed correlations. However, it has been shown that, at least for the summertime months, interannual changes in dustiness over the North Atlantic are related to changes in Sahel precipitation from the previous year and are not strongly correlated with same-year Sahel precipitation events ((73)). (20) suggest that because dust is a good tracer for the Saharan Air Layer, these observed correlations may result from the effect of the Saharan Air Layer acting as a control on cyclone activity in the Tropical Atlantic, consistent with the hypotheses of (15). It is worth noting that the variability in the dust time series may not only reflect variations of the presence of the Saharan Air Layer, but it may also reflect changes in dust loadings within the Saharan Air Layer itself, which could also have important meteorological implications. It is interesting to note that a 5 to 8 year oscillating behavior is also seen in the dust record, superimposed over a downward trend in dustiness.

In contrast to the dynamic effects of the Saharan air layer (SAL) in suppressing cyclogenesis, (58) suggest an extensive cooling over the subtropical North Atlantic may be related to the shielding of′ solar radiation (the so-called solar dimming effect) by dust. They exemplify with the particular behavior of the hurricane season in 2006, when it was expected a continuation of the trend of nine preceding years of above- normal hurricane seasons, however, the 2006 hurricane season was near normal with four tropical storms and five hurricanes, but decidedly much fewer as compared with the record numbers of 12 tropical storms and 15 hurricanes in 2005, including Katrina. Given the recent warming tendency in the Atlantic and the prevailing favorable preseason conditions: sea surface temperature (SST) was above normal, vertical wind shear was low, and sea level pressure was reduced over the tropical Atlantic, at the beginning of the season, all signs indicated that it would be more active than the 2005 season. Though in overall, the dust loading in 2006 was higher than in 2005, by the beginning of June there was a major increase in dust loading, and two 2 weeks later occurs a major episode of SST cooling, concomitant with a long-term trend to warming . Even if the 2006 SST in the

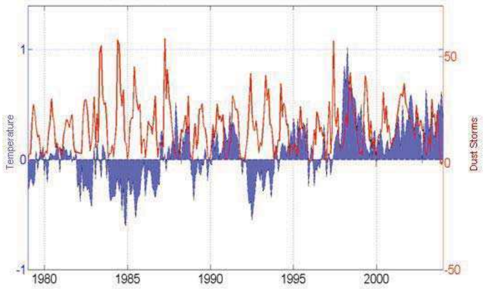

Fig. 7. Superficial Sea Temperature vs Dust Storms (1979 − 2004)

Atlantic Ocean was above normal compared with the long-term climatology, there was an abrupt cooling of the Atlantic from 2005 to 2006 independently of the long-term variation. It can be seen in Fig. 7 that AD storms could be seen as a cooling factor of the Atlantic ocean superficial waters except during the periods 1990 − 1992, 1994 − 1996, 1998 − 2004, when both signals AD and SST do increase. The most pronounced SST cooling began in mid-June 2006, reaching a maximum in late June and mid-July, until the end of September after which the SST returned to the 2005 level. The cooling was widespread, covering most of the subtropical and equatorial North Atlantic, with the strongest signal ($\sim 0.6^o - 0.8^oC$) over the WAC (western Atlantic and Caribbean). The SST cooling of the North Atlantic appeared to be closely related to the variation of Sahara dust over the region: a substantial increase in atmospheric dust loading covering nearly all the northern tropical and subtropical Atlantic and western Africa with the oceanic maximum over the western Atlantic and Caribbean, where the negative SST anomaly was most pronounced. The major dust episode lasted for about a month, until the end of June. In 2006, no hurricanes were found over the WAC and the Gulf region.

(20) has objected the role of Sahara dust in triggering a series of rapid feedback processes in the ocean-atmosphere system resulting in unfavorable conditions for hurricane formation in the Atlantic in 2006. The main point is, how much initial dust radiative forcing is enough to trigger the feedback process?. By an analysis of the aerosol optical thickness of the region in 2005 and 2006, (59) estimated an increase of 28 − 30% in 2006 relative to 2005, what is translated in a reduction of surface solar shortwave radiation flux of $4.3 - 8\ watts\ m^{-2}$. Such values could explain the required forcing. Whether there is a direct or indirect link remains elusive, since no direct causality has been yet established. Some authors suggests the variability in dust (and variability in the presence of the Saharan Air Layer), and others claim a solar dimming effect by Saharan dust as linking mechanisms for the changes in North Atlantic tropical cyclone activity. However, if up to day there is not a conclusively direct causal relationship, there is conclusive evidence of robust link between tropical cyclone activity and dust transport over the Tropical Atlantic.

5. Signal theory as a tool to find common connections among different phenomena

We have mentioned in the previous sections some work that, by means of a correlational analysis, seems to indicate that certain extraterrestrial phenomena could have some kind of relation with the terrestrial phenomena, and particularly with the occurrence of Hurricanes ((17), (43), (44),(45) and (46)). It is even claimed that such kind of connections could seat the basis of deeper studies to use the results as indicators of hurricanes precursors. To

give to those results a higher meaning, it is convenient to carry out spectral studies of the different involved times series to delimitate with more preciseness the existence of those potential relationships. With this goal in mind we use here Signal Theory tools, searching to determine the most prominent signals between North Atlantic hurricanes of all categories, the Sea-Surface Temperature (SST), the Atlantic Multidecadal Oscillation (AMO), African Dust (AD) for one side, and Solar Activity (SS) and Galactic Cosmic Rays (GCR) for other side.
Such analysis leads to establish the evolution in frequency and time, as well as the phase between two time series of those phenomena, allowing inferring the nature of any connection among them. That is, to find incident cosmophysical periodicities that may modulate terrestrial phenomena. As the question about the role of the Sun in modulating these phenomena has not been clarified, it requires further assessment. In the next sections we describe the investigations done on the behavior of the main common periodicities among the AMO, SST, AD, solar activity phenomena (SS), Galactic Cosmic Rays (GCR) and hurricanes. Here, as before, in the correlational analysis, it is assumed that, if there is a good interconnection between the studied terrestrial phenomena and hurricanes, and on the other hand, there is a good interconnection between these terrestrial phenomena and cosmophysical phenomena, therefore it should be also a good interconnection between hurricanes and cosmophysical phenomena.

6. Methods of analysis

The simplest and widely known technique to investigate common periodicities between two series of data is the Fourier Transform, the Fast Fourier transform and Regression Analysis. However, while useful for stationary time series, these methods are not the best for time series that are not of stationary nature ((35); (116), (117)), as those analyzed in this work. A nice description of the limitations and drawbacks of Fourier Analysis, (including the short-time-Garbor or the windowed Fourier transform, and the kindness of the wavelet transform was given by (83). In contrast to those methods, one of the most powerful tools to work with non-stationary series in Signal Theory is the so called Wavelet Spectral Analysis: within this context in order to find the time evolution of the main frequencies within a simple non stationary series at multiple periodicities the Morlet-Wavelet technique is a useful technique for analyzing localized variations of power spectrum ((116); (30)). A way to analyze two non-stationary time series, to discern whether there is a lineal or non-linear relation is by means of the Coherence-Wavelet method which furnish valuable information about when and which periodicity do coincide in time, and then about its nature, lineal or non-linear relation between the given series (for instance, solar and terrestrial phenomena), provided there is not a noticeable diphase among them. The Wavelet coherence is especially useful in highlighting the time and frequency intervals where two phenomena have a strong interaction.

6.1 The Wavelet Tranformer

In order to analyze local variations of power within a single non-stationary time series at multiple periodicities, such as the dust or hurricanes series, we apply the Wavelet (WT) using the Morlet wavelet ((116)). The Morlet wavelet consists of a complex exponential modulated by a Gaussian $e^{i\omega_o t/s}\, e^{-t^2/2s^2}$ where t is the time, with $s = 1/frecuency$ is the wavelet scale and ω_o is a non-dimensional frequency. Here it is used $\omega_o = 6$ in order to satisfy the admissibility condition ((22)). (116) defined the wavelet power $|W_n^x|^2$, where W_n^x is the wavelet transform of a time series X and n is the time index. The power spectra for each one of the parameters described in the study of next sections was computed using a Morlet wavelet as a mother wave. For the Morlet Wavelet spectrum, the significance level is estimated for each scale, using only values inside the cone of influence (COI). The COI is the region of the wavelet spectrum where edge effects become important: it is defined as the e-folding time for the autocorrelation at each scale of the wavelet power. This e-folding time is chosen such that, the wavelet power for a discontinuity at the edge drops by a factor e-2, and ensures that the edge effects are negligible beyond that point ((116)). Wavelet Power Spectral Density (WPSD) is calculated for each parameter; the contour of this cone marks the interval of 95% confidence, that is, within the COI. To determine significance levels of the global wavelet power spectrum, it is necessary to choose an appropriate background spectrum.

6.2 The Coherence and the cross wavelet

For analysis of the covariance of two time series x and y, such as the dust and hurricanes series we used the cross wavelet $W_k^{xy}(\psi)$ (XWT), which is a measure of the common power between the two series. The cross wavelet analysis was introduced by Hudgins et al (1993). Torrence and Compo, (1998) defined the cross wavelet spectrum of two time series X and Y, with wavelet transforms (W_n^x) and (W_n^y), as $W_n^{xy} = W_n^x W_n^{y*}$, where $(*)$ denotes complex conjugation. The cross wavelet energy is defined as $\left|W_n^{xy}\right|$. The complex argument is the local relative phase between X and Y in time-frequency space. Torrence and Webster, (1999) defined the cross-wavelet power as $\left|W_n^{xy}\right|^2$. The Coherence $(R^2(\psi))$ is a number between 0 and 1, and gives a measurement of the cross-correlation between two time-series and a frequency function. Statistical significance level of the wavelet coherence is estimated using Monte Carlo methods with red noise to determine the 5% significance level ((117)). The coherence significance level scale appears at the bottom of the figures of next sections.

6.3 The wavelet transformer coherence

The wavelet-squared transform coherency (WTC) is especially useful in highlighting the time and frequency intervals, when the two phenomena have a strong interaction ((116), (117)). The wavelet square coherency $(R^2(\psi))$ is defined as the absolute value squared of the smoothed cross-wavelet spectrum XWT , normalized by the smoothed wavelet power spectra. Unlike the cross wavelet power, which is a measure of the common power, the wavelet square coherency is a measure of the intensity of the covariance of the two series in time-frequency space ((116)).

The WTC measures the degree of similarity between the input (X) and the system output (Y), as well as the consistency of the output signal (X) due to the input (Y) for each frequency component. When $R^2(\psi) = 1$ or ~ 1, this indicates that all frequency components of the output signal (Y) correspond to the input (X) and means that there is synchronization between output signal (X) and input signal (Y). The synchronization can be in phase, frequency and/or amplitude. If $R^2(\psi) \ll 1$, then output Y is not related to input X because of the presence of noise, nonlinearities and time delays in the system.

6.4 The signal/noise wavelet coherence transformer

The coherence of the system can be calculated through the relation signal/noise, defined as ($WTC_{s/n}$) in (122). The $WTC_{s/n}$ is just what we are using in this work, because it allows us to find linear and nonlinear relationships, while verifying that the periodicities of cross-wavelet are not spurious, in order to minimize the effects of noise. If the XWT and the $WTC_{s/n}$ of two series are enough high, the arrows in the XWT and $WTC_{s/n}$ spectra show the phase between the phenomena:

a) Arrows at 0^o (pointing to the right) indicate that both time series are correlated (in phase) and arrows at 180^o (pointing to the left) indicate that they are anticorrelated (in anti-phase). It is important to point out that these two cases imply a linear relation between the considered phenomena.
b) Non horizontal arrows indicate an out of phase situation, meaning that the two studied phenomena do not have a linear relation but a more complex relationship ((122)).

6.5 The wavelet global spectra

On the right blockls of figures of next sections, it is shown the global spectra, which is an average of the power of each periodicity in both the wavelet and the coherence spectra (GXWT and $GWTC_{s/n}$). It is usually used to notice, at a glance, the global periodicities of either the time series, or, of the coherence analysis. The significance level of the global wavelet spectra is indicated by the dashed curves, they refer to the power of the red noise level at the 95% confidence that increases with decreasing frequency ((30)). It is a way to show the power contribution of each periodicity inside the COI, delimiting the periodicities that are on, or, above the red noise level. The uncertainties of the periodicities of both global wavelet and coherence spectra are obtained at the half maximum of the full width peak. As in the Morlett wavelet, the 95% confidence level of the coherence is inside the black contour (the COI).

7. Coherence analysis of terrestrial and cosmophysical forcings

Data.- To assess the long-term relations between space phenomena and indicators of the global climate it is often necessary to use reconstructions of Galactic Cosmic Rays (CR), solar activity (SS) and climate phenomena. Direct measurements of solar activity based on sunspot numbers exist since 1749, but trustable CR data is only available since the $1950s$ decade when the neutron Monitor Stations began to operate. Records of climatic phenomena exist from the end of the 19th century.
For the AMO the annual time series between $1851-1985$, data from the World Data Center for Paleoclimatology is used here: ($http : //www.ncdc.gov/paleo/$). For Solar Activity we use the daily number of Sun spots number (SS): http://www.ngdc.noaa.gov/stp/SOLAR/ftpsunspotnumber.html#american). Concerning the ^{10}Be, there is a polemic about whether it can be considered as a Proxy of Galactic Cosmic Rays (see for instance. (107), (108)). Nevertheless, a good number of researchers still support the use of ^{10}Be as a Proxy of CR (e.g. (123); (64); (64); (119), (120)) etc. Under this last context we have considered the ^{10}Be concentration in the Dye 3 ice core ($65.2N, 43.8W, 2477m$ altitude) from (2), which data for the period 1851-1985 were offered to us by the author. Regarding data of Hurricanes the WEB page $http : //weather.unisys.com/hurricane/$ has been considered.
The analysis results are displayed through the next panels. The upper block of each figure shows the time series of the data involved. The power level color code used throughout this paper is indicated at the bottom of each panel. Areas inside black contours correspond to the 95% significance level. As we are working with two time series, the wavelet coherence and phase difference are obtained. As the blocks of the wavelet coherence indicate the time and frequency intervals where two phenomena have a strong interaction. The global spectra (on the right blocks of each figure) allows us to notice at a glance the global periodicities of either the time series or the coherence analysis. The significance level of the global spectra is indicated by the dashed curves. It refers to the power of the red noise level: peaks below the line implies a global periodicity with a confidence lower than 95% at the corresponding frequency, whereas peak for above indicates a confidence level higher than 95% at the given frequency. The Spectral power (abscissa axis) is given in arbitrary units.

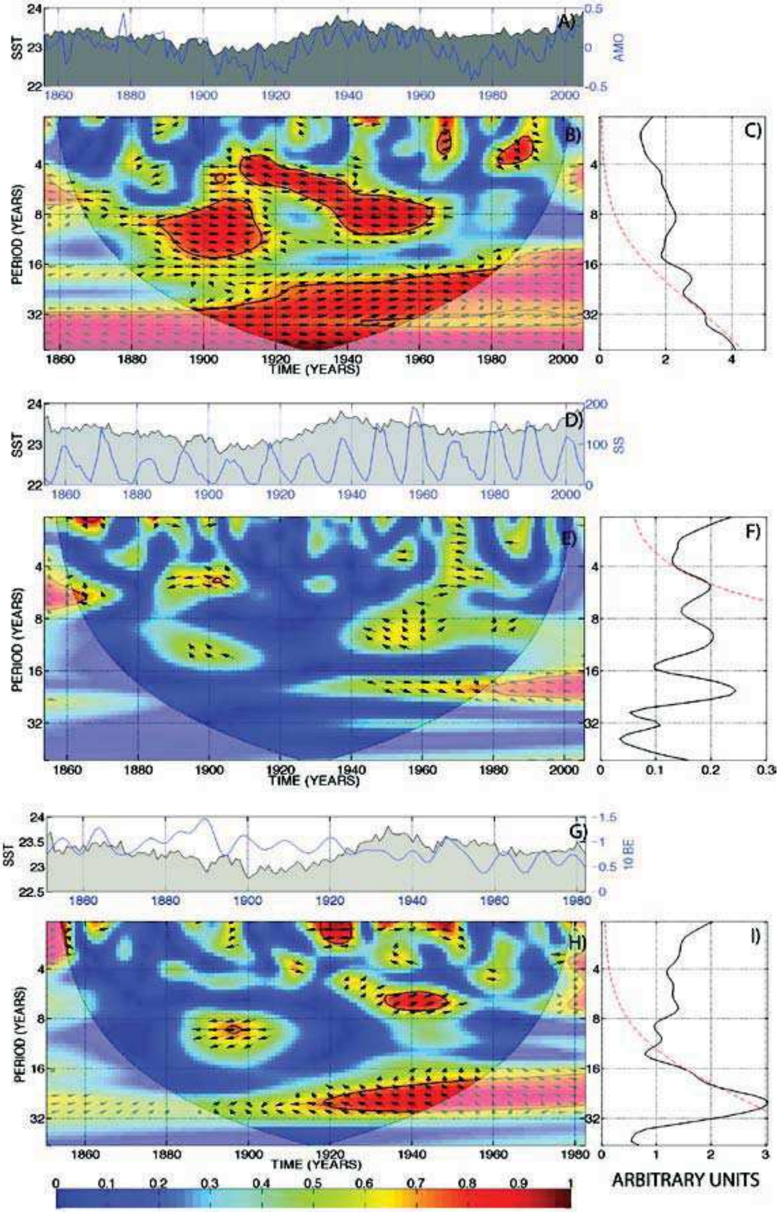

Fig. 8. (A) Time series of AMO (blue line) and SST (gray area). (B) Coherence between SST and AMO. (C) Significance level of the global spectra of SST and AMO. (D) Time series (blue line)of SS and SST. (E) Coherence between SST and SS. (F) Significance level of the global spectra of SST and SS. (G) Time series of SST and CR (^{10}Be) (blue line). (H) Coherence between SST and CR (^{10}Be). (I) Significance level of the global spectra of SST and CR (^{10}Be)

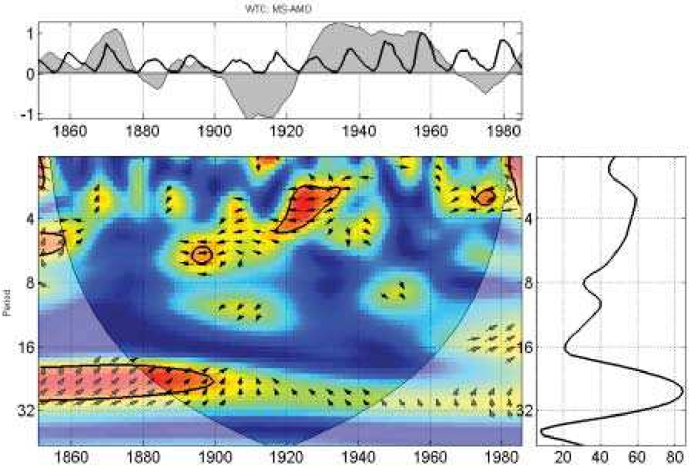

Fig. 9. Upper block: Time series of AMO (gray area) and SS (black line) . Lower block: Coherence between SS and AMO . Right Block: Global Spectrum

The main results that can be drawn from (Fig. 8) can be summarized as follows:
1) There is a coherence of 0.95 inside the COI between the AMO and SST anomalies through the band of $15-32$ years, in the time interval $1900-1980$ (Figs. VI.2.B-C). The oscillation in the 30 years frequency is completely in phase, indicating a lineal relation among both phenomena, which is not surprising because is something very well known by climate specialists.
2) There is a coherence of 0.6 between the SST anomalies and SS, also limited to short intervals, $1895-1910$, $1945-1960$ at the frequency of 11 years with tendency to be in anti-phase, and $1940-1980$ at the 22 years frequency, with tendency to be in phase (Figs. VI.2E-F). It can be seen from these figures that no frequency at the 30 years periodicity was found for Solar Activity (at least through the use of SS), by means of the wavelet spectral analysis.
3) There is a coherence of 0.90 inside the COI between SST anomalies and ^{10}Be (the CR proxy) at the 30 years frequency, in the time interval $1920-1950$ (Figs. VI.2H-I) for the case of SST anomalies. The oscillations have a tendency to be quasi-perpendicular, indicating a complex relation among both terrestrial phenomena and CR. It can be mentioned that the same frequency is found among AMO and ^{10}Be in the period $1870-1950$, but with a lower coherence of ~ 0.75 (Fig. 6a in (121)).
From Fig. 9 it can be seen that there is a non-linear coherence of 0.90 inside the COI between the AMO and SS near the 30 years frequency, in the time interval $1875-1895$. This is gradually attenuated during the minimum of the modern secular solar cycle ($1890-1940$), with a coherence of 0.55 and a complex phase between the oscillations. Also, there is a quasi linear anti-phase linear coherence < 0.80 at the frequency band $3-7$ years in the period $1890-1915$ reaching a coherence > 0.9 from $1915-1930$.

8. Coherence analysis of terrestrial and cosmophysical forcings vs cyclones

Results from panel (Fig. 10) can be summarized as follows:
1) There is a coherence of 0.9 inside the COI at the 7 years frequency, between the total number of hurricanes (i.e., including all magnitudes from TS to all together) and the SST anomalies

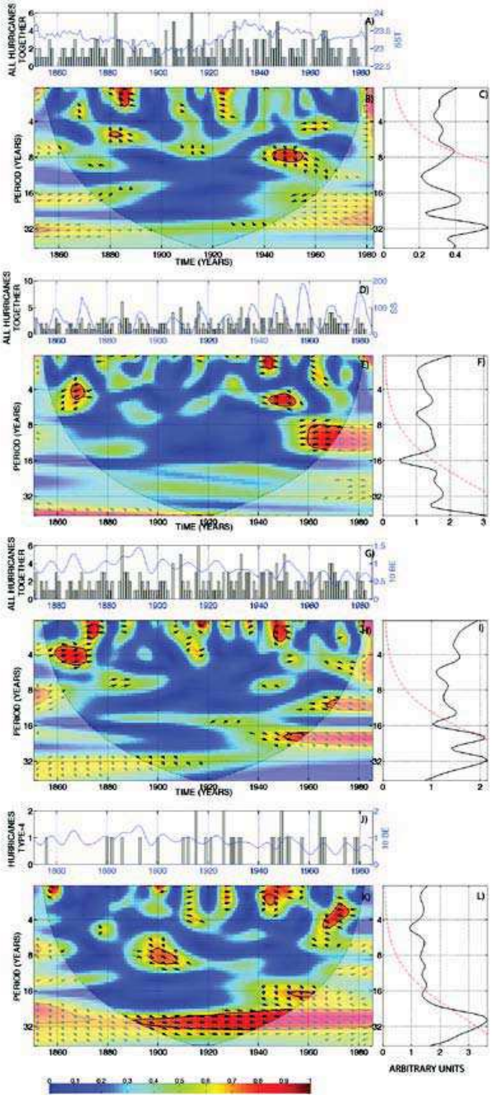

Fig. 10. (A) Time series of SST and all Hurricanes together. (B) Coherence between SST and all Hurricanes together. (C) Significance level of the global spectra of SST and all Hurricanes together. (D) Time series of SS and all Hurricanes together. (E) Coherence between SS and all Hurricanes together. (F) Significance level of the global spectra of SS and all Hurricanes together. (G) Time series of CR (^{10}Be) and all Hurricanes together. (H) Coherence between CR (^{10}Be) and all Hurricanes together. (I) Significance level of the global spectra of CR (^{10}Be) and all Hurricanes together. (J) Time series of CR (^{10}Be) and Hurricanes of magnitude-4. (K) Coherence between CR (^{10}Be) and Hurricanes of magnitude-4. (L) Significance level of the global spectra of CR (^{10}Be) and Hurricanes of magnitude-4.

However this is only limited to the time interval 1945 − 1955. This is illustrated in Figs. VII.1.B-C, for the case of SST anomalies. The oscillations have a tendency to be in anti-phase, indicating a lineal relation of both phenomena with hurricanes. 2) The coherence between SS and Hurricanes of all magnitudes together is about 0.9, limited at the frequency of 11 years during the period 1955 − 1965, (E-F in Fig. 10). However, the analysis of SS vs hurricanes of individual magnitudes gives relatively low values of coherence inside the COI.

3) The coherence at the frequency of 30 years, between CR (through the proxy (^{10}Be) with hurricanes of all magnitudes together is about 0.6 in the period 1890 − 1940 (H-I in Fig. 10). In contrast those of $5, 11, 22$ reach a coherence of 0.9 in the intervals 1860 − 1870, 1960 − 1970 and 1950 − 1960 respectively.

4) For some hurricanes, as for instance those of magnitude-4, the coherence with CR (^{10}Be) is > 0.9 at the 30 years frequency, during a relatively long period, 1890 − 1950 (K-L in Fig. 10). In these cases there is a tendency of the oscillations to be in-phase, indicating a linear relationship among both phenomena.

9. Coherence of African Dust vs Cyclones

In order to rise the relevance of extraterrestrial influence on hurricane phenomena, it is needed a frame of reference. We consider here, as such a frame a terrestrial phenomenon which is well established to be related with cyclone development, as is the case of the Dust Cover originated in African Dust Outbreaks (e.g., (20), (58), (7)). Hence, the results shown on the next figures correspond to the spectral analysis of coherence, by the wavelet method mentioned before, for Atlantic tropical cyclones of all categories, versus African Dust Outbreaks ((122)).

Though there has existed satellite data on AD since the 1980, here we use only multidecadal continuous in-situ monthly data available from Barbados from 1966 up to date ((87), (90)). Monthly data of hurricanes was taken from the national Weather Service and transformed into a dates series of pulses ((122)) as: n = number of hurricanes, where 0 = no hurricane. Both data series are shown in blocks (a) of Fig. 11 and Fig. 12. On the next figures the global spectra are shown on the left side blocks.

The GXWT [panel (b) of Fig. 11] between dust and Category 5 hurricanes shows a very prominent annual periodicity with confidence higher than 95%. As can be seen in the XWT [panel(c)], this periodicity presents a high variability; it is not continuous and doesn't have the same intensity throughout the 1966-2004 period, becoming more intense during the 1970s and at the beginning of the 1980s, just when Category 5 hurricanes were, average, the most intense. This annual periodicity is presumably related to the dust cycle in North Africa and to seasonal changes in atmospheric circulation ((37)). Additionally, there is a decadal periodicity (11-13 years), which is present throughout the entire time interval with an anti-correlation tendency [panel(c)]. Its temporal tendency can be observed in panel (a) of Fig. 10 with a dotted line obtained by means of a Daubechies type modified wavelet filter (122)). This decadal periodicity is presumably related to the Atlantic trade wind variations and the dominant meridional mode of SST variability in the tropical Atlantic ((103)), as well as with with solar activity ((34) and cosmic rays ((81)) . The interaction of solar activity and cosmic rays with hurricanes is probably accomplished through the modulation of the Atlantic multidecadal oscillation (Perez08a).

This decadal variation shows that Category 5 hurricanes occur around the decadal minimum [panel (a)], because the local vertical wind shear ($Vz > 8m/s$) is unfavorable for the genesis of tropical cyclones ((9)). This would explain why from 2008 up to the present, there have not been any Category 5 hurricanes, since it was precisely during this time that African dust in the atmosphere has been increasing. This would imply that if such a tendency continues, the

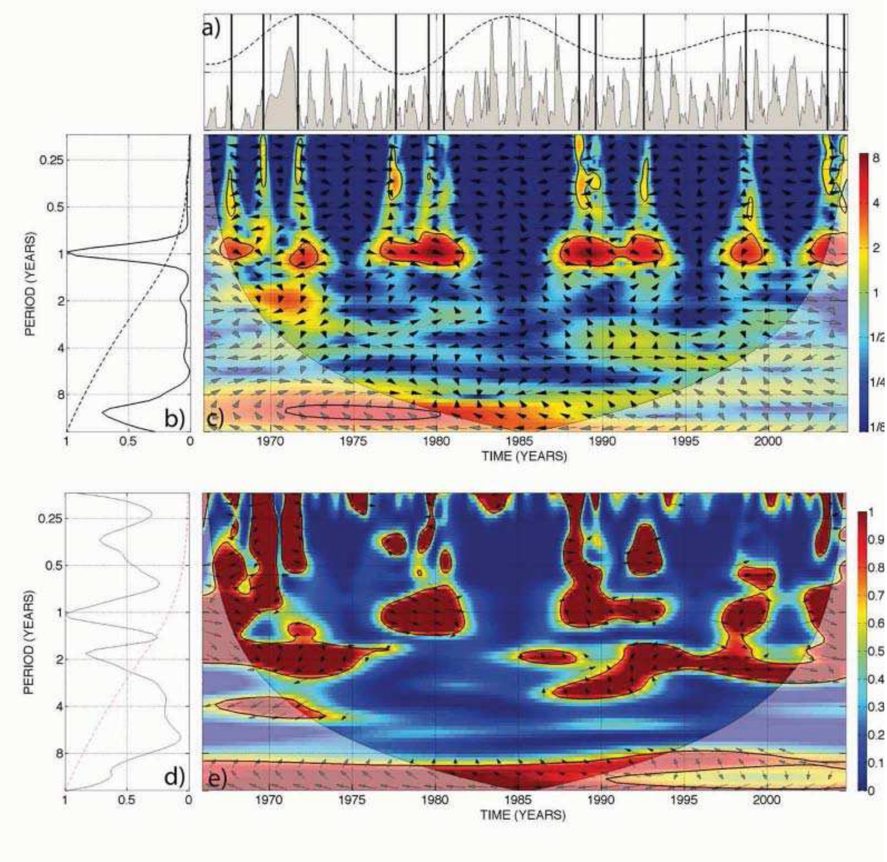

Fig. 11. (a) Time series of African Dust (shaded area). - Category 5 hurricanes (black bars) - decadal tendency of dust (dotted line). (b) global cross-wavelet coherence, GXWT. (c) cross-wavelet coherence XWT, (d) global wavelet-squared transform coherency (signal/noise), GWTCs/n. (e) wavelet-squared transform coherency (signal/noise), WTCs/n. ((122))

next group of tropical cyclones will not evolve to category 5 until the next decadal minimum of African dust occurs. To confirm if the annual and decadal periodicities obtained with the cross-wavelet are intrinsically related to the modulation of African dust on Category 5 hurricanes, we also obtained the modified wavelet coherence (WTCs/n) and found, in addition to these two periodicities, two others, of 125 days and 1.8 years with a confidence level higher than 95% [panels (d) and (e) of Fig. 11].

Fig. 12 shows the GXWT (panel b) between dust and tropical storms where it can be seen that the most prominent periodicity is that of 1 year. These annual variations do not have the same intensity throughout the period studied, as can be observed in the XWT (panel c) when the periodicity was low and parsimonious from the second half of the 1960s up to the first half of the 1970s, due to an increase in precipitation in North Africa. At this point, the coherence becomes very intense due to the very severe droughts in West Africa, known as the Sahel

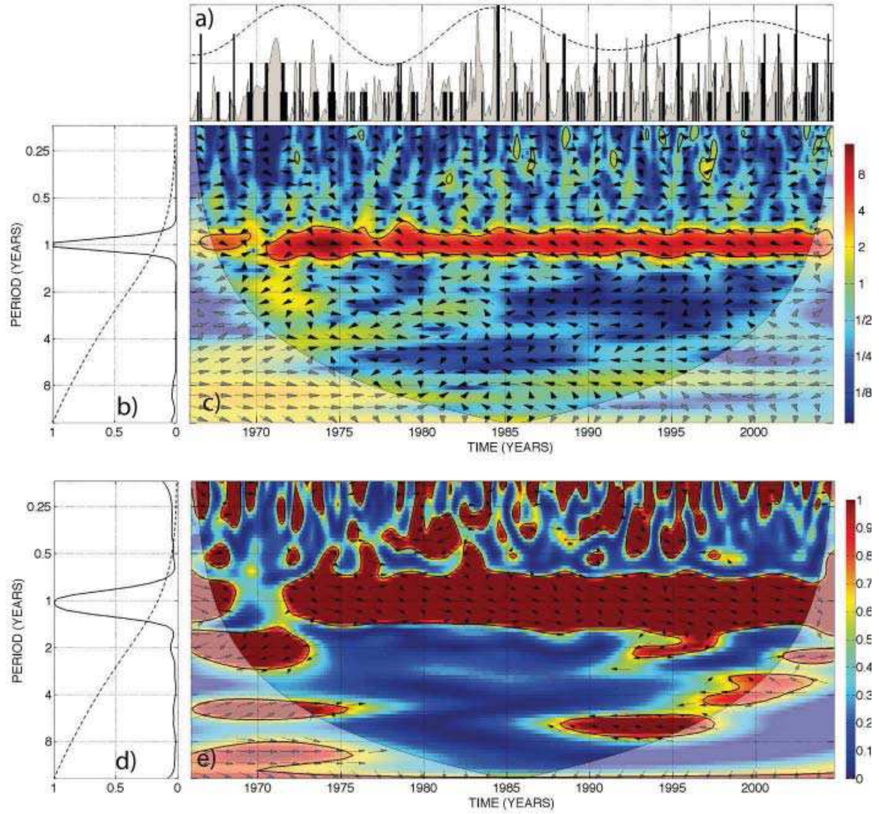

Fig. 12. (a) Time series of African Dust (shaded area). - Tropical Storms (black bars) - decadal tendency of dust (dotted line). (b) global cross-wavelet coherence, GXWT. (c) cross-wavelet coherence XWT, (d) global wavelet-squared transform coherency (signal/noise), GWTCs/n. (e) wavelet-squared transform coherency (signal/noise), WTCs/n. ((122))

drought, that began in the middle of the 1970s and lasted for several decades. The in-phase behavior of this annual periodicity with a linear tendency seems to indicate that variability in dust has a quasi-immediate effect on the genesis and evolution of tropical storms. There are other periodicities lesser and greater than 1 year but with inconsistent patterns. This may be interpreted as that dust concentration and the evolution of tropical storms are the result of many external and internal factors occurring on different time scales. The XWT and WTCs/n show that the multiannual periodicities, including the decadal periodicity, are not essential factors in the formation of tropical storms.

The global GXWT and WTCs/n (panels b and d), as well as the cross-wavelet and coherence (panels c and e) between dust and Category 1 hurricanes (Fig. 4 in (122)) show a great deal of similarity with tropical storms, though with different intensities. These differences may be due to the increase of precipitation in North Africa, as indicated by the Sahel rainfall index. Decadal periodicity is absent for Category 1.

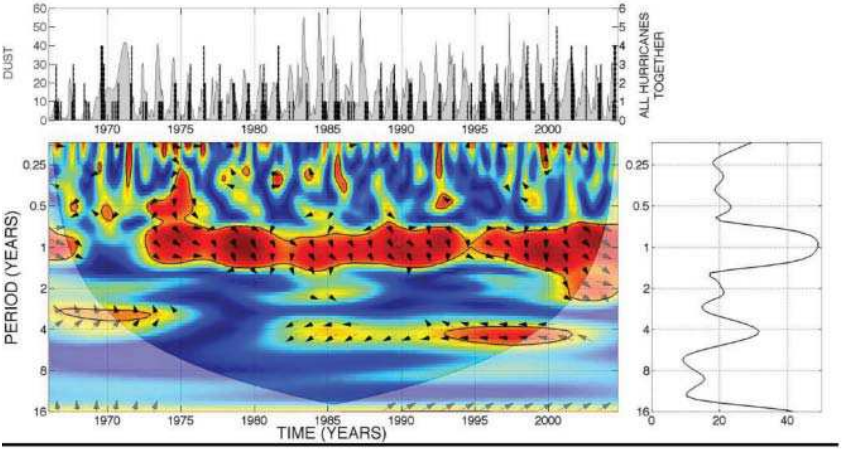

Fig. 13. Time series of African Dust (shaded area) - all hurricanes categories together (black bars). The lower panel is wavelet-squared transform coherency (WTC), and the right panel is the Global spectrum GXWT.

It can be observed in Fig. 5 in (122) that the GXWT and GWTCs/n (panels b and d), as well as the XWT and WTCs/n (panels c and e) between dust and hurricanes for category 2 show an annual periodicity that has a less continuous time interval as compared to Category 1 hurricanes and tropical storms (Fig. 12), becoming more intense from 1972-1982 and 1988-2004. Additionally, there exist less prominent periodicities of 3.5-5.5 years that are associated with the El Niño Southern Oscillation (ENSO) . Decadal periodicity is absent for Category 2 hurricanes.

The GXWT and GWTCs/n (panels b and d), as well as the XWT and WTCs/n (panels c and e) in Fig. 6 and Fig. 7 (in (122)) between dust and Category 3 and 4 hurricanes, respectively, show that the annual periodicity is also not continuous over the period studied. It can also be observed in panel (e) that the periodicity of 3.5 years for Category 3 hurricanes becomes more intense during the interval 1980-1992. For Category 4 hurricanes the periodicities of 3.5-5.5 years (panel e) are anti-correlated during 1988-2002. Decadal periodicities for Category 3 and 4 hurricanes are practically absent.

It should be emphasized that the observed correlations show not only a direct effect of African dust on hurricane activity but also reflect an indirect relationship between the wind, SST, AMO, the Modoki cycle, El Niño, la Niña, precipitation, solar activity and cosmic rays that to a greater or lesser degree modulate the evolution of Atlantic hurricanes.

10. Coherence between cosmic rays and cyclones

For comparison of the influence of CR on Cyclones with the influence of AD on Cyclones (for which the period time is relatively short 1966 − 2005), it is not necessary to use a Proxy for CR, since data of NM stations is quite confident since the later 50*s*. Therefore we use data from the worldwide NM station network. in units of counts/min that we transform to monthly and annual data. Here below we present results corresponding to annual data.

The results obtained in section 11 as compared with those of section 10 can be summarized as follows:

1) It can be seen on Figs. 12 and 14 for Tropical Storms, that the coherence is higher and more continuous in time with AD than with CR.
2) It can be appreciated from Figs. 4 (in (122)) and 14 for hurricanes of magnitude-1, that the coherence with Dust is very high, of the order of 1, almost during all the studied period, but a shot , in the period $1996 - 1999$ is only observed with CR, with a coherence higher than 0.9 at the 2 years frequency.
3) For Hurricanes of magnitude-2 the coherence with CR is 0.7 years, in short periods, with a coherence near 0.8, again stronger than with Dust (Figs. 5 in (122)) . Fig. 14 (G) - (H)), show that the coherence with AD is > 0.9 at the periodicity of 1 year in anti-phase all the studied period.
4) For Hurricanes of Magnitude-3, it can be seen from Fig. 14 (J)-(K) that the dominant periodicity after 1973 is in 0.6 years, for short time periods, whereas for AD it can be seen from Fig. 6 (in (122)) that the coherence is > 0.9 at the 1 year periodicity, in anti-phase all the time .
5) For Hurricanes of Magnitude-4, (Fig. 14 (L)- (O)) shows that the coherence with CR is of the order of 0.95 and is in anti-phase at the periodicity of 1.7 years in limited time intervals . Coherence with AD at the frequency of 1 year, with a coherence > 0.9 after 1973 (Fig. 7 in (122)).
6) For the more dangerous hurricanes, those of magnitude-5 we can see from Fig. 14 (P)-(R) that the coherence is of complex nature, in the 0.7 and 1.7 years periodicities, in short time intervals, with a coherence around 0.9. From Fig. 11 we can see that coherence is of the order of 1 at the 1 and $10 - 11$ years periodicity always in anti-phase. The 1 year periodicity occurs mainly in limited periods, occurring every 10 years.
7) It can be seen from Figs. 14 (T) and 14 (S)-(U) that the coherence between all kind of Atlantic hurricanes together (from Tropical Storms to magnitude-5) and cosmic rays is at the 1.3 and 1.7 yrs frequencies. Variations seem to be in phase from 1987 to 1991 with coherence of 0.6, and suddenly they switch in anti-phase during $1996 - 2002$, with coherence higher than 0.9.
8) In contrast to previuos statement (7) on Fig. 13 it is shown that the coherence between all kind of Atlantic hurricanes together and the African Dust Outbreaks is more continuous than with CR , with coherence higher than 0.9, and it is concentrated around the 1.3 and 4 years periodicities, for long time periods, with complex non-linear phases. Moreover, it should be mentioned that the red noise of the confidence level of the global spectrum in Fig. 13 is not shown, because it is far above the frequency picks.

11. On the genesis of the category-5 Atlantic Hurricanes: "The geography of the marine bottom"

Fig. 15 shows a map of the barometric distribution of the eyes of Category 5 hurricanes illustrated for six of these kind of hurricanes, between 2005 and 2007: Wilma (2005), Rita (2005), Katrina (2005), Emily (2005), Dean (2007) and Felix (2007). The black circles at the right side column indicate the evolution of each hurricane, from Category 1 to 5, during their trajectory. ((122)).

By tracing the trajectories of all hurricanes, we have delimited the existence of four areas of deep water in the Atlantic Ocean where the eye of the hurricane has the lowest pressure ($<920mb$): I) the east coast of the United States, II) the Gulf of Mexico, III) the Caribbean Sea and IV) the Central American coast. This must be pointed out because it implies that, in addition to the required climatological conditions for the genesis of this kind of Category 5 hurricanes to take place, the geography of the marine bottom also plays an important role, and that these hurricanes do not originate in hazardous places (Fig. 14). ((122)).

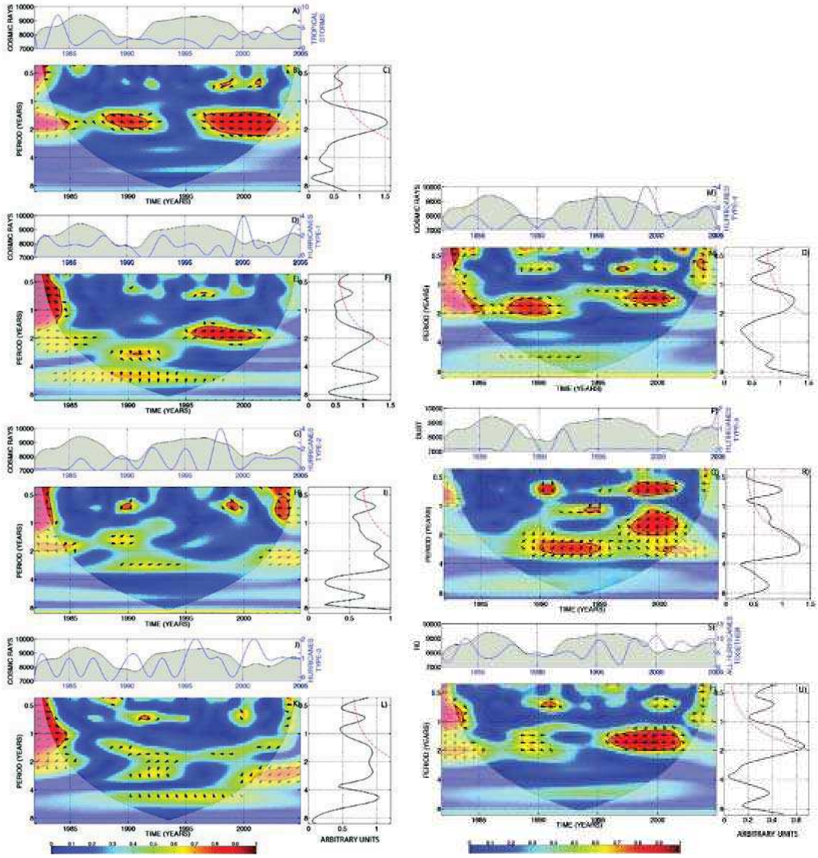

Fig. 14. A) Time series of CR and Tropical Storms. (B) Coherence between CR and Tropical storms. (C) Significance level of the global spectra of CR and Tropical Storms. (D) Time series of CR and Hurricanes of magnitude-1. (E) Coherence between CR and Hurricanes of magnitude-1. (F) Significance level of the global spectra of CR and Hurricanes of magnitude-1. (G) Time series of CR) and Hurricanes of magnitude-2. (H) Coherence between CR and Hurricanes of magnitude-2. (I) Significance level of the global spectra of CR) and Hurricanes of magnitude-2. (J) Time series of CR and Hurricanes of magnitude-3. (K) Coherence between CR and Hurricanes of magnitude-3.(L) Significance level of the global spectra of CR and Hurricanes of magnitude-3. (M) Time series of CR and Hurricanes of magnitude-4. (N) Coherence between CR and Hurricanes of magnitude-4. (O) Significance level of the global spectra of CR and Hurricanes of magnitude-4. (P) Time series of CR and Hurricanes of magnitude-5. (Q) Coherence between CR) and Hurricanes of magnitude-5. (R) Significance level of the global spectra of CR and Hurricanes of magnitude-5. (S) Time series of CR and Hurricanes of all magnitudes together. (T) Coherence between CR and Hurricanes of all magnitudes together. (U) Significance level of the global spectra of CR and Hurricanes of all magnitudes together

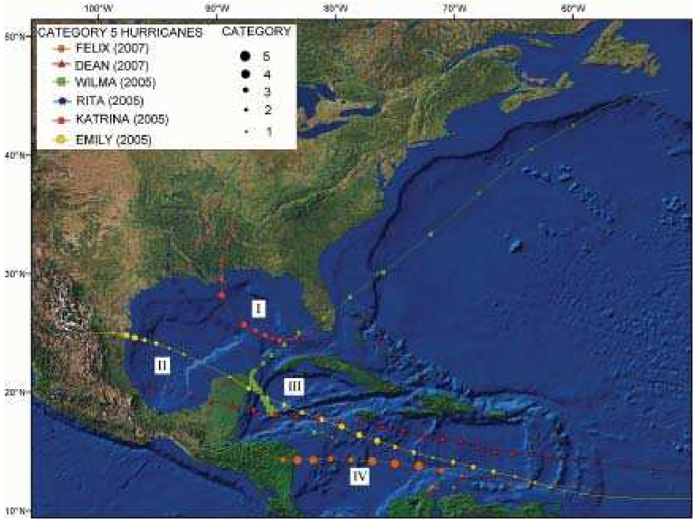

Fig. 15. Map of the Atlantic Ocean centers of cyclogenesis of Category 5 hurricanes: I) the east coast of the United States, II) the Gulf of Mexico, III) the Caribbean Sea and IV) the Central American coast ((122)).

12. Discussion

Keeping in mind that the quasi-anticorrelation between SST and Dust Storms (Fig 8) is not a perfect one and that a linear correltaion between SST and North Atlantic Cyclones (Fig. 10 (B)-(C)) is also not perfect, but the anti-phase situation is systematically found between AD and hurricanes, then we assume here, in first instance, that the more abundant the AD storms the fewer the number of North Atlantic Cyclones, and conversely, a linear correlation would mean that the more abundant the AD storms the higher the occurrence of cyclones, at least they were completely independent phenomena, which seems not to be the case.

In this context, the spectral analysis carried out here for the study of common periodicities among Cosmic Rays and phenomena which are presumably associated with Hurricanes (AMO and SST-anomalies) is in agreement with previous results ((80), (81)). We have found that there are common periodicities between some extraterrestrial and terrestrial phenomena, namely 3.5, 5.5, 7, 11 years and the more prominent one, that of 30 yrs. is often present (as can be seen in most of Figs. 9, 10) with exception of SS. It should be mentioned that no figure with Dust shows the 30 year periodicity, because data 13 Dust only cover 40 years. Such a periodicity is also present in CR vs Hurricanes of Type-4 as was shown in (81), where the applied Morlet-wavelet technique allowed to put in evidence, for the first time from a Coherence wavelet study, the periodicity of 30 years in cosmic ray fluctuations. The most dangerous Hurricanes do not show that periodicity, since confident data on category-5 exist only since 1980. It should be mentioned that this frequency is also found in other indexes of hurricane activity, as has been previously mentioned. Preliminarily, it can be speculate that this 30 years cycle may be associated to a semi-phase (either of the maximum or the minimum) of the Secular Cycle of 120 years of Solar Activity, that is, half of the so called Yoshimura-Gleissberg cycles ((131), (121)).

If the coherences found in this work among the studied phenomena, may be interpreted as a modulator factor, then, from the analysis of the previous results it could be speculated that the modulator agent of terrestrial phenomena is the open solar magnetic field , translated in GCR (via the ^{10}Be). This modulation seems to be more important in the period $1880 - 1960$. That does not mean there is no modulation after and before, but according to the coherence wavelet technique the significance level is lower than 95%.

It seems then that GCR are modulating in some way both the SST and AMO (Fig. 9) and Fig. 6a in (121)), and these in turn modulate in some way hurricanes as it can be seen from the Coherence wavelet analysis (Fig. 10 (B)-(C)) which confirms the conventional statement of hurricanes to be linked to warmer oceans. We then assume here that the action of GCR on the clouds is an additional warming factor of the SST and AMO, as it does the greenhouse gases on the earthÕs surface temperature (95), which in some way is to be translated in the development of hurricanes. In contrast, the indicator of closed solar magnetic field (via SS) presents, within the COI, a lower and attenuated coherence with the terrestrial phenomena.

13. Conclusion

The spectral analysis carried out here for the study of common periodicities among Cosmic Rays and phenomena which are presumably associated with Hurricanes (AMO and SST-anomalies) is in agreement with previous results ((80), (81)). We find again that the frequency of 30 years is often present with exception of the SS graphs. Though, it is well known that cosmic rays and solar activity phenomena are inversely related in time, such a relation is not directly translated on their influence on hurricanes development. The temporal scale of their influence is certainly different: cosmic rays influence is a relatively prompt effect, whereas solar activity seems to act as a result of a slower buildup effect ((79)); it should be appreciated the good coherence between CR and hurricanes of all magnitude, particularly with those of magnitude-4. In contrast, the indicator of closed solar magnetic field (via SS) does not present the 30 year periodicity, but it presents (within the COI) a very low and attenuated coherence with terrestrial phenomena, at the frequencies of 3.5, 5, 7, 11 and 22 years (Figs. 9, 10 (E)-(F)).

Nevertheless, the analysis must be extended with data of other solar indexes, (as for instance, radio in 10.3 cm and coronal holes) versus specific parameters of the hurricanes (vorticity, linear velocity, duration, energy, power destruction index, PDI, accumulated cyclone energy, ACE, and storm intensity). There is also the possibility that the periodicity of 30 years could be associated in a non-linear way to the solar Hale Cycle ((98)) with a certain phase shift.

Also, we would like to state that though we cannot say in a conclusive way, that CR modulates the AMO and SST, we must keep in mind that the AMO has intrinsic periodicities (at least since 1572) at 30, 60, 100 years ((121)) and the AMO is in turn a modulator of the SST ((109)). Because, the only other phenomena that we know that present such periodicities are SS and CR, we infer that such a modulation of AMO and SST may be related to one or both cosmophysical phenomena.

In order to estimate the relevance of cosmophysical influence on hurricane activity we have compared it with the African Dust outbreaks (sections 8-11) and found that the coherence, at similar frequencies, is in many cases higher with AD than with CR, though the influence of CR is not at all negligible. However, Cosmophysical influences cannot be disregarded, and may eventually become of the same order of importance of some terrestrial effects, thought it seems not to be the case for the dust cover originated in African dust outbreaks. Furthermore, the fact that two data series (cosmophysical and climatic) have similar periodicities does not necessarily imply that one is the cause and the other the effect: a physical mechanism must be behind, able to give an explanation of such coincident signals. Since such interconnections are still in the stage for establishment of trustable evidences, it is perhaps still no time to look for physical mechanisms.

Finally, special mention must be done to the results of section 10, from where we can conclude that African dust influence on the genesis and evolution of Atlantic hurricanes varies in two main ways: (a) annually for tropical storms and hurricanes of all categories and (b) decadally for Category 5 hurricanes ((122)).

Category-5 hurricanes develop during the minimums of decadal cycles of African dust, when winds are lower than $8m/s$, and Ocean temperatures are around 26^oC.

Recent studies ((122)) seems to indicate that category-5 Atlantic hurricanes are not random events, neither in time nor in space, and that in addition to peculiar climatological conditions, the geography of the Ocean bottom is an important factor in the development and evolution of Category 5 tropical cyclones, since at least in fout Atlantic dee-water regions, hurricane eyes have the lowest pressure. Every category 4 hurricane crossing in some segment of its trajectory throughout one or more of these four regions will evolve to a category 5 hurricane.

Finally, it is worth mentioning that if climatologically tendencies continue as they have done in recent decades, according to our analysis [see panel (a) of 9] future hurricanes will not be able to develop into category 5 until the next decadal minimum, that will begin around 20152 years .

14. Acknowledgments

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