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Sunspots Production and Relation to Other Phenomena: A Review

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ABSTRACT

The subject of sunspot activity is of great scientific importance because many scientists believe that it has a direct impact on human life on Earth. There are many theories and interpretations and statistics through which scientists try to establish a relationship between the activity of sunspots and agricultural activity, economic, health and behavior of humans. Climate change on the planet is currently one of the most controversial and debates not only among scientists but also among politicians. Some experts also believe that global warming is due to reasons of human activities, although the real causes of this phenomenon are not yet known. Preliminary studies on this phenomenon have shown that global climate change is not only a ground phenomenon but also due to solar system activity, the sun particular. In this study, the Solar Cycle concept is introduced and the sunspots mechanism is reviewed. The origin of the Solar Magnetic Cycle and Sunspot Characteristics are discussed. The Solar Storm Background is introduced followed with concluding remarks.

INTRODUCTION

Sunspots are dark patches on the Sun where intense magnetic fields loop up through the surface from the deep interior. The earliest actual recordings of sunspot observations were from China over 2000 years ago. Yet, the existence of spots on the Sun came as a surprise to westerners when telescopes were first used to observe the Sun in the early 17th century. This is usually attributed to western philosophy in which the heavens and the Sun were thought to be perfect and unblemished. The first mention of possible periodic behavior in sunspots came from Christian Horrebow in 1776. Although Christian Horrebow mentions this possible periodic variation the solar (sunspot) cycle was not truly discovered until 1844. In that year Heinrich Schwabe reported that his observations of the numbers of sunspot groups and spotless days over the previous 18 years indicated the presence of a cycle of activity with a period of about 10 years. Figure 1 shows his data for the number of sunspot groups observed yearly from 1826 to 1843. These data led Schwabe to his discovery of the sunspot cycle.[1]

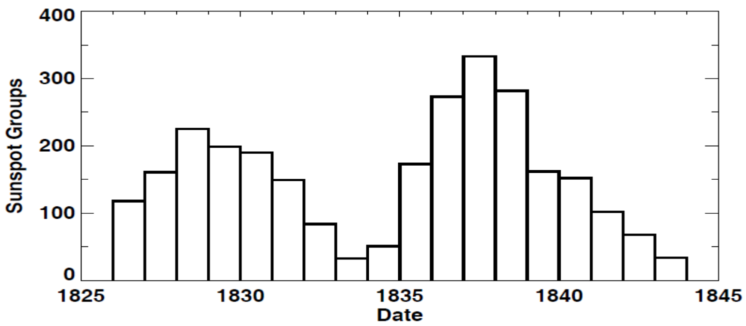

Figure 1: Sunspot groups observed each year from 1826 to 1843[1].

Figure 2 illustrates the solar cycle and shows that it varies in amplitude, shape, and length. Months with observations from every day are shown. In 1908 Hale discovered strong magnetic field in sunspots (B about 3000 G). In 1955 Parker formulated dynamo theory for the origin of astronomical magnetic fields [1].

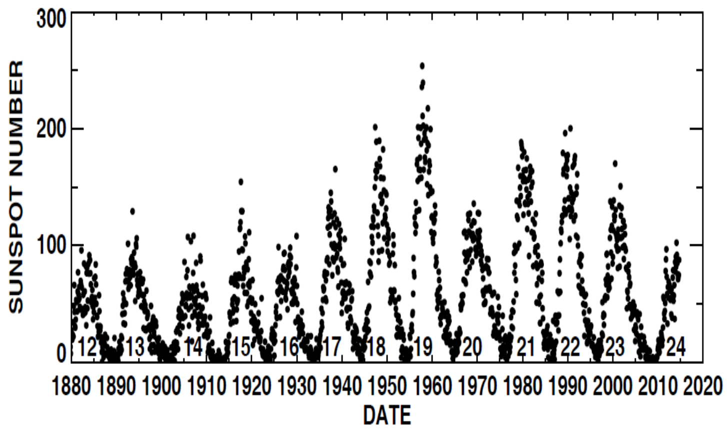

Figure 2: Monthly averages of the daily Sunspot Number. Months with 11 – 20 days of observation

MATERIALS AND METHODS

As a source of energy, the Sun continuously provide inhabit environment to our planet Earth. As an enormous enclosed sphere radiating spectrum of different wavelengths, it fulfilled the basic requirements of providing different present species with survival needs, for that reason, early human beings created myths around the sun. The Sun also exhibited phenomena such as the Flares, Corona Mass Ejection (***CME***), Solar wind, and the Sunspots. These phenomena play great roles, other roles start emerging, while other factors may be disclosed in future. Now it is known that all these phenomena relate to the Sunspots, which in turn represents part of the Sun's strong and complex magnetic field [2].

The Sunspots production and relation to other phenomena generates many debates and speculations, some of which explain the phenomenon within available related knowledge, with lack of alternative theory, and some add complexity to Sunspot mechanism and related phenomena. Solar activities resulted from the interaction of ionized solar plasma with the magnetic field produced by these plasma [2], thus it is interlocked relation created by the plasma.

The basic knowledge of the solar system mechanism is crucial and essential for the survival of humankind, and we can't properly understand other stars and life elsewhere if we failed to understand mechanism that regulates our sun. As an energy generator, the Sun engulfed with related knowledge in a mystic phenomenon, which required different tools to help penetrate deep beneath the Sunspots [2].

In 2003, three important satellites were launched to study the Sun, the astonishing footages by NASA's Solar Dynamics Observatory (***SDO***) and others, showed the dynamics of energy process in Sun's peripheries, these outstanding wealth of knowledge, as it generate questions, which will never reflects positively on human progress if never get proper answers and foundation to build upon. Analyses of data obtained from these satellites have led to conclusion that an Interplanetary-External Magnetic Field is produced within the magnetosheath and other spatial areas within the interplanetary space, these finding shows an independent mechanism for local production of Interplanetary-External Magnetic Field, which is not related to the fields from the sun[2]. Although sunspots complexity was deepened by the difference between what is seen on solar photosphere and the long internal mechanism producing the phenomenon. Sunspots knowledge has been approached differently by the suggestion that what lay beneath the sunspots is a pillar shape structured from the plasma. Based on fundamental physics as introduced by The Magnetic interaction hypothesis has led to an entirely new hypothesis for energy transformation [2]. This important aspect has laid the bases upon which solar activities and External Magnetic Field could better be understood [2].

The Sun is composed mainly of plasma (electrons and protons), hydrogen, helium and other elements. It is thought to consist of the core, radioactive, tachocline and convection zones (see figure 3.).

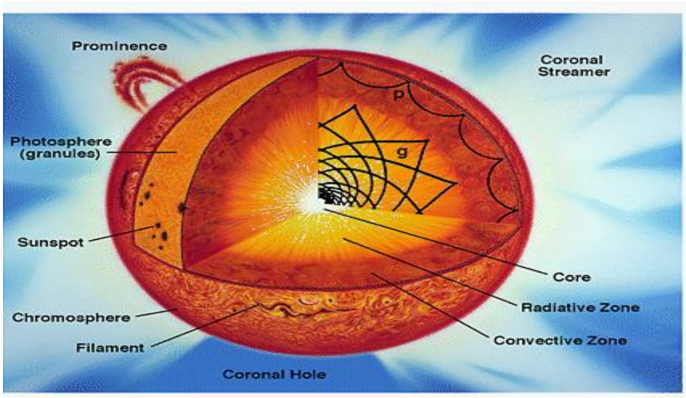

Figure 3. Sunspots are magnetic field concentrations in turbulent plasma [3]

Solar main known characteristic was the Sunspots, which is explained as resulted from twisting magnetic lines and the Dynamo process (see figure 4) [2].

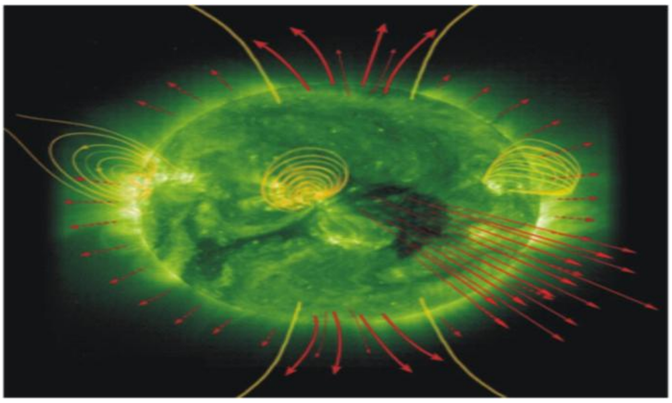

Figure 4. Magnetic lines of force in the Sun [2].

- However, the electrons in the compressed plasma are propelled with such velocity that they trigger intense X-Ray emissions as they pass hot ions (Bremsstrahlung) (see figure 5).

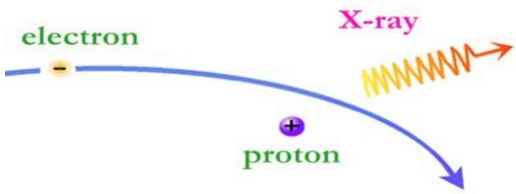

Figure 5. Bremsstrahlung process [2]

- In addition, the electrons coil around field lines, which in turn produces oscillatory emission in the form of Radio Waves (Synchrotron)(see figure 6).

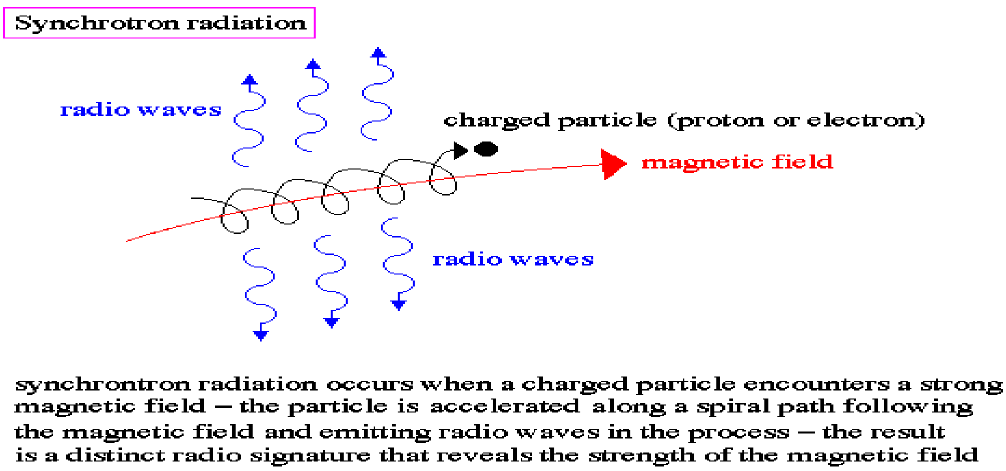

Figure 6. Production of radio waves [2]

- Recall that the Sun is rotating differentially with far more variation than the Earth. (see figure 7.)

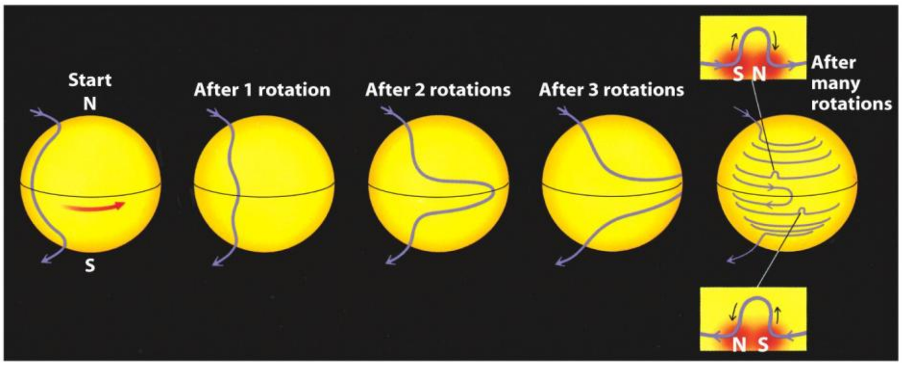

Figure 7. Sun differential rotation [4]

- Just as in the Earth, the motions of plasma in the deep convection zone generate a magnetic field.

- The solar field is produced closer to the 'surface' and is affected by rotation more strongly.

- This has some impressive consequences for the Sun.

- At the equator, the Sun rotates once every 25 days. At the poles, it rotates every 36 days.

- Because the plasma inside the Sun is bound to the rotation of the neutral convection zone, the magnetic field is going to be stretched out by the differential rotation of the Sun [4].

The sun generates solar flare and Coronal Mass Ejection (CME) events in an approximate 11-year cycle. The plasma clouds generated from these events have the potential to cause geomagnetic storms that can interfere with terrestrial communications and other electronic systems, posing a risk to critical infrastructure (see figure 8).

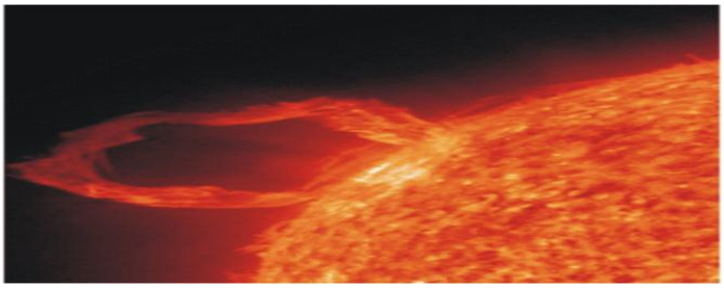

Figure 8. The famous prominence eruption of March 2010, captured by NASA's Solar Dynamics Observatory (SDO). The upper toroidal magnetic field attracted by the lower intense sunspot [2]

In a recent case, Earth-orbiting satellites detected the strongest magnetic storm in more than 4 years resulting from a solar flare and CME event. Figure 8 illustrates the size of the CME shockwave edge in relation to the size of the sun at the point of the eruption. The explosion that produced this flare also sent a solar tsunami rippling through the sun's atmosphere and hurled a CME toward Earth. CME activity will continue to occur as this solar cycle progresses (see figure 9.).

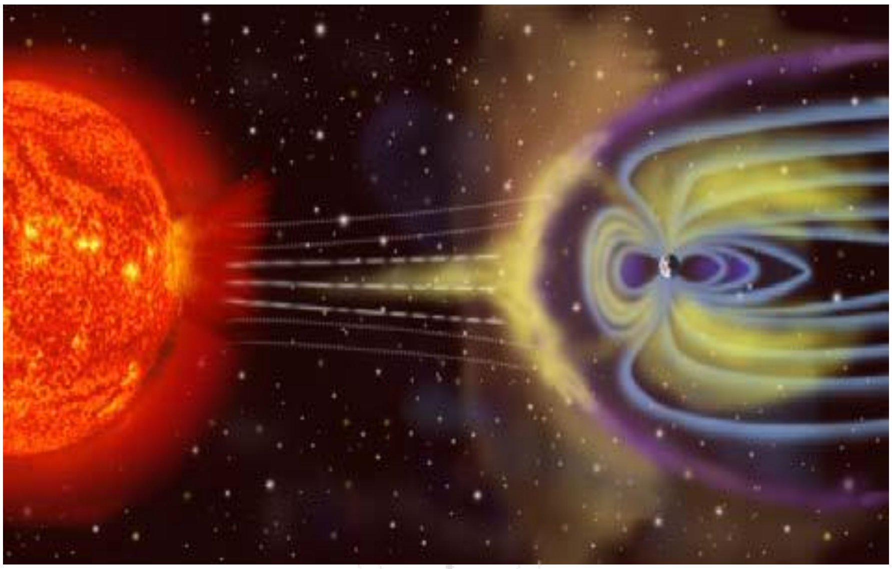

Figure 9. Solar flare and coronal mass ejection at the time of the eruption. By the time the CME reached the Earth, the shockwave leading edge had expanded to approximately 40 million miles across [5].

The sunspot characteristics can be summarized as follows:

- Sunspots are **transient** features in the solar atmosphere. Their total number changes with time as well.
- Sunspots are typically ***paired*** on the surface of the Sun.
- They are often seen ***connected to filaments*** on the surface
- They are clustered near the ***middle regions*** of the Sun and rotate with it (see figure 10).
- Sunspots are not 'dark', but ***cool*** (about 3000K).[4]

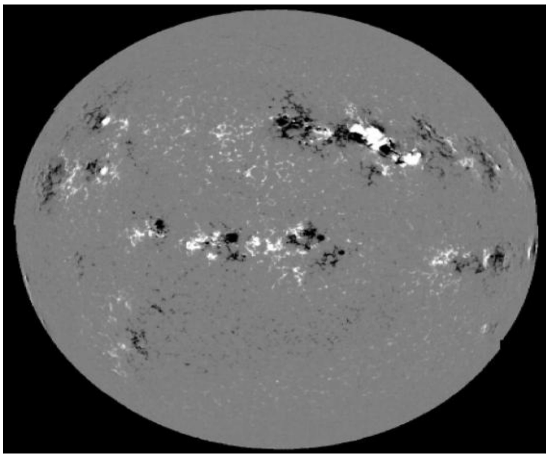

Figure 10. Magnetogram map (white +ve, black –ve) Polarity is opposite from one 11-yr cycle to next 22-yr period [4].

The number of sunspots waxes and wanes on an 11 year cycle. Orientation flips every 11 years too (N-S→S-N) to (S-N→N-S). It takes 22 years for orientation to flip and return to previous state [4].

- The dark center of the sunspot is called Umbra (see figure 11)
- The lighter color region surrounding the umbra is called Penumbra
- Diameter = 20,000---60,000 km
- Magnetic field orientation

• Umbra vertical field

• Penumbra inclined field [4]

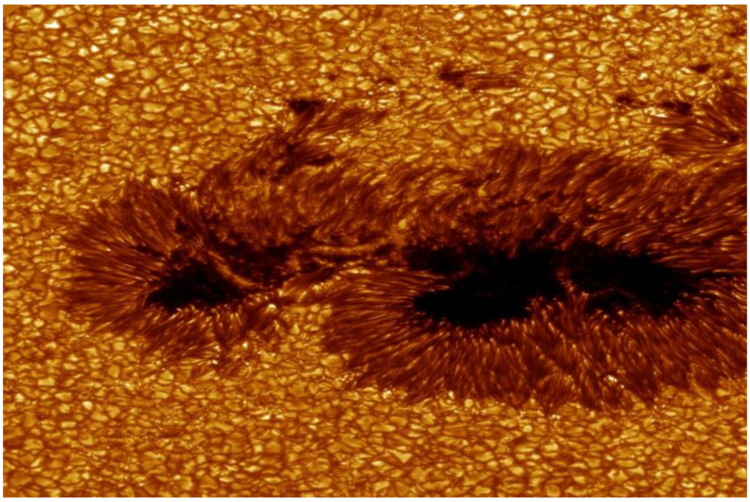

Figure 11. Sunspot showing Umbra and Penumbra [4]

- This process takes some time, but eventually, the field gets wrapped up, just like a tetherball. And the Sun's magnetic field bounces back.

- Sunspot number is tied to how wrapped up the field is by differential rotation. (see figure12).

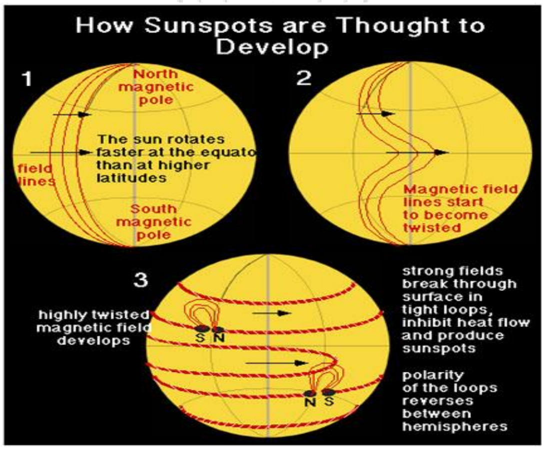

Figure 12. Sun's magnetic field Sun wrapped up by differential rotation

- Sunspot characteristics make a lot of sense when we consider the magnetic Sun

- The region where sunspots form is where the field gets the most wrapped up.

- The orientation of the N-S pairs is due to the orientation of the solar field and how it changes with cycle.

- Flares occur in regions of rapid magnetic field re-alignment [4](see figure 13).

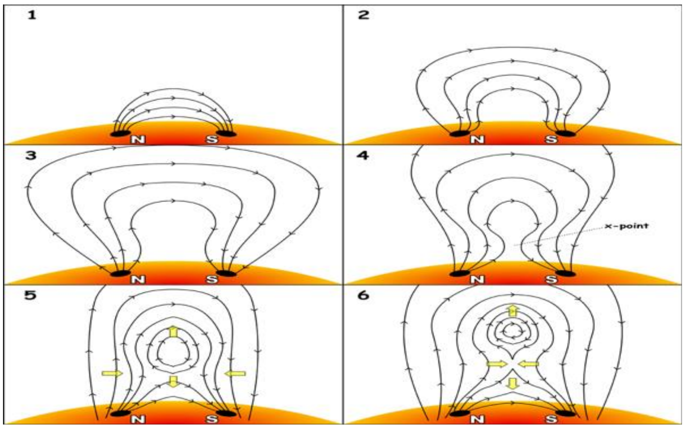

Figure 13. Coronal loop development [4]

1. Coronal loop
2. Field begins to inflate
3. Field twists as sunspots move at different speeds due to differential rotation
4. Field begins to pinch inwards (field lines of opposite sign attract)
5. Magnetic field breaks due to shear forces
6. Plasma blob is accelerated upward and additional plasma is accelerated back towards the chromosphere[4](see figure 14)

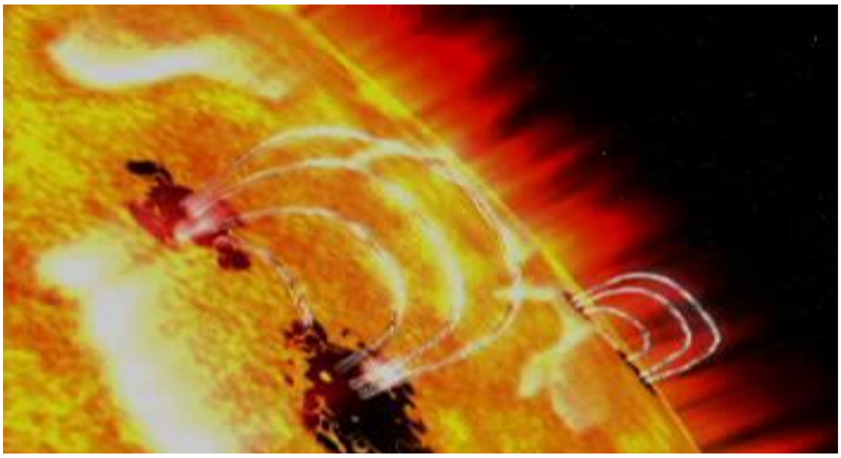

Figure 14. An image of Coronal loop [4]

Solar events associated with sunspot activity fall into three categories: (i) Solar flares involve a powerful burst of radiation (X-rays, extreme UV rays, gamma rays and radio frequency waves) that heats and increases the ionization of the upper atmosphere. Solar flares cause interference with satellite communications, radar, and shortwave radio. The radiation burst travels at the speed of light, reaching the Earth about 8 minutes after the eruption the largest measured solar flare occurred on November 4, 2003. (ii) Solar Proton Events (SPE) follow the flares. They travel at sunlight speeds, reaching the Earth about 1 hour after the eruption. A SPE involves high-energy cosmic rays (protons and ions) that can disorient satellites, damage spacecraft electronics, interfere with shortwave radio in the Earth's Polar Regions, and deplete the atmosphere's ozone layer. (iii) CMEs involve large clouds of charged plasma with an embedded magnetic field whose leading edge can expand to nearly 40 million miles across by the time it reaches the Earth. CME shockwaves travel at various speeds, some at nearly 5 million miles per hour, reaching Earth in about 18 hours or more [5].

The ionosphere (the upper layer of the atmosphere, 85 to 600 kilometers above the Earth) is critical to radio signal propagation. Solar radiation creates the ionosphere by ionizing the upper layer of the atmosphere. Broadcast radio transmissions reflect off the ionosphere to reach the intended receiver. When the magnetic field associated with a CME impacts the Earth's magnetic field, the resulting geomagnetic storm can last several days, with storm effects continuing 1 to 2 days more. The CME's electromagnetic energy disrupts the ionosphere's reflectivity, adversely impacting broadcast radio signal transmissions.

This can also affect Global Positioning System (GPS) satellite signals, interfering with the GPS timing reference used by navigation systems and many control systems. As a geomagnetic storm impacts the Earth's magnetic field, it generates potential differences across the surface because of variations in the Earth's resistivity. The electromagnetic field from a CME changes the potential difference in power distribution and transmission system ground-to-line voltages, producing Geomagnetic-Induced Currents (GIC) that can damage the large connected transformers used at power plants and substations [5].

Geomagnetic storms can interfere directly with GPS and radio communication because of the ionosphere disturbances. The interference can range from induced noise to complete signal loss. Geomagnetic storms can indirectly affect many other systems, including control systems that rely on GPS or radio technologies. Control systems that employ the following technologies may experience partial or complete service outages of varying durations, depending on the intensity of the storm. [5]

The continuing trend toward transmitting more electrical power over longer transmission lines, closer to maximum power limits, creates a directly proportional relationship between the intensity of a geomagnetic storm and electric grid impact. A geomagnetic storm can cause severe problems for electrical power systems during their peak hours of operation. During a solar storm, the CME plasma cloud and its magnetic field collides with the Earth's magnetic field, causing large transient magnetic disturbances. These disturbances, or geomagnetic storms, can affect the Earth's magnetic field for as much as 2 days. The geomagnetic storms can induce voltage variations along the Earth's surface, creating potential differences in voltage between grounding points that cause GICs to flow through transformers, power transmission lines, and grounding points. Regions of low conductivity, such as the regions of igneous rock geology that are more susceptible to geomagnetic storm affect. Power transmission systems built in those areas experience significantly larger GICs from geomagnetic disturbances.

Solar storms can affect pipe-to-soil voltages, leading to currents that disturb flow meter signals, which can result in false pipeline flow rate data. The induced currents can also increase pipeline corrosion rates. Insulating flanges meant to interrupt current flow create an additional point where electric potential can result in current flow to ground, increasing the risk for corrosion [5].

Solar storm interference may impact rail Supervisory Control and Data Acquisition (SCDA) system dispatch operations and communication networks that employ wireless technologies, especially those dependent on GPS timing signals. Engineers and field maintenance personnel will need to coordinate efforts during the CME event, especially if the decision is made to run systems in manual mode.

As a long-term approach, owners and operators of industrial control systems that are reliant on GPS timing signals should consider including integrated backup timing systems to accommodate the temporary loss of GPS because of interference or actual failure.

Interference with GPS navigation and position information may also impact critical infrastructure in the oil and gas industries' marine fleets, where exploration activities often require precise station keeping operations. Vessels may be equipped with bottom fix capability as a redundant functionality. However, when the ship control system does not include bottom fix capability, mitigation may require suspending operations until the solar storm subsides [5].

The concept of the perfectness and constancy of the sun, postulated by Aristotle, was a strong belief for centuries and an official doctrine of Christian and Muslim countries. However, as people had noticed even before the time of Aristotle, some slight transient changes of the sun can be observed even with the naked eye. Although scientists knew about the existence of "imperfect" spots on the sun since the early 17th century, it was only in the 19th century that the scientific community recognized that solar activity varies in the course of an 11-year solar cycle.[6]

The sun is the only star, which can be studied in great detail and thus can be considered as a proxy for cool stars. The use of the sun as a paradigm for cool stars leads to a better understanding of the processes driving the broader population of cool sun-like stars. Therefore, studying and modeling solar activity can increase the level of our understanding of nature.

On the other hand, the study of variable solar activity is not of purely academic interest, as it directly affects the terrestrial environment. Although changes in the sun are barely visible without the aid of precise scientific instruments, these changes have great impact on many aspects of our lives. In particular, the heliosphere (a spatial region of about 100 astronomical units) is mainly controlled by the solar magnetic field.

Additionally, eruptive and transient phenomena in the sun/corona and in the interplanetary medium can lead to the acceleration of energetic particles with greatly enhanced flux. Such processes can modify the radiation environment on Earth and need to be taken into account for planning and maintaining space missions and even transpolar jet flights. Solar activity can cause, through coupling of solar wind and the Earth's magnetosphere, strong geomagnetic storms in the magnetosphere and ionosphere, which may disturb radio-wave propagation and navigation-system stability, or induce dangerous spurious currents in long pipes or power lines. Another important aspect is the link between solar-activity variations and the Earth's climate [6].

RESULT AND DISCUSSION

It is important to study solar variability on different timescales. The behavior of solar activity in the past (see figure15), before the era of direct measurements, is of great importance for a variety of reasons. For example, it allows an improved knowledge of the statistical behavior of the solar-dynamo process, which generates the cyclically varying solar-magnetic field, making it possible to estimate the fractions of time the sun spends in states of very-low activity, what are called grand minima. Such studies require a long time series of solar-activity data. The longest direct series of solar activity is the 400-year-long sunspot-number series, which depicts the dramatic contrast between the (almost spotless) Maunder minimum and the modern period of very high activity. This allows one to study the temporal evolution of solar magnetic activity, and thus of the solar dynamo, on much longer timescales than are available from direct measurements [6]. Although sunspots have been extensively studied for almost 400 years and their magnetic nature has been known since 1908, our understanding of a number of their basic properties is still evolving, with the last decades producing considerable advances [7].

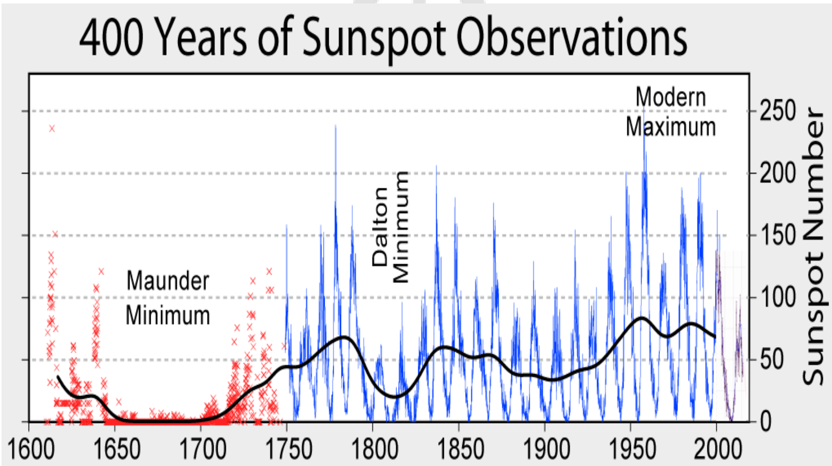

Figure 15. Sunspot observations [8]

During the Maunder Minimum periods of low solar sunspot activity, there was also an increase in the ratio of radio-carbon 14 (^{14}C) to ^{12}C in tree rings and there were documented changes in the aurora borealis. Each of these periods was known for the sometimes bitterly cold and prolonged winters in the Northern Hemisphere. The Maunder Minimum occurred during most of the 17th Century and the first decade or so of the 18th Century [9]. A later period of relatively low sunspot activity commenced in the last two decades of the 18th

Century and lasted for the first three decades of the 19th Century. This period is known as the Dalton Minimum. The two grand minima were collectively called the "Little Ice-Age". Radio-carbon 14 is produced when a high energy proton hits a nitrogen atom and beryllium 10 can be produced when it hits either oxygen or nitrogen. Only some protons that have originated from outside the solar system can have the energy to produce these radio-nuclides [9].

Many studies have suggested the sunspot activity influences on Nature's Risks, and explain how the decreased levels of sunspot activity will affect long-term weather risks as well as long-term earthquake and volcanic risks [9]. The aim of these studies is to encourage the actuarial profession to develop skills in space weather forecasting and understand the risk management activities that stem from such abilities. Also to understand why, at certain times, when solar flares that hit Earth, they have the ability to temporarily significantly change climatic conditions, earthquake and volcanic risks. Understanding just these mechanisms should convince the profession to develop important real-time risk management tools and capabilities that can be applied in many areas of our expertise as well as in new areas where actuaries so far do not have a role. But there are many more space-age data sets and that we should understand and use. Understanding how natural forces (in particular the current prolonged low sunspot activity of the sun) affect a number of risks that should interest actuaries. These include human mortality, natural events such as major earthquakes and volcanic eruptions, direct weather related risks, in particular, from weather extremes [9].

There are a second category of risks that are important. These include risks relating to food and energy security, the political risks arising from unaffordable increases in the price of these commodities, crop insurance and other forms of insurance that are affected by climatic extremes. There is also the risk that if our profession does not recognize the risk implications of these changes in the sun our reputation could be significantly impaired [9]. Understanding the sun-climate connection requires a breadth of expertise in fields such as plasma physics, solar activity, atmospheric chemistry and fluid dynamics, energetic particle physics, and even terrestrial history. No single researcher has the full range of knowledge required to solve the problem.

Figure16. shows how in "normal" conditions the upper troposphere (10 km above sea level in mid-latitudes) has a temperature of about -50° C, the stratosphere (from 10 km to 50 km above sea level) gradually warms to about 0° and the mesosphere (50 km to about 88km

above sea level) gradually cools to about -100° C. The thermosphere (88km to 500 km above sea level) then warms to about 450-500° C.

The exosphere and the ionosphere are influenced by particulate (hydrogen and helium atoms and ions) emissions from the sun via the solar wind. The thermosphere mainly consists of ions (of oxygen and nitrogen) which are created by EUV photon emissions. EUV and FUV emissions also reach the lower levels of the atmosphere if they don't collide with non-ionized molecules in the thermosphere.

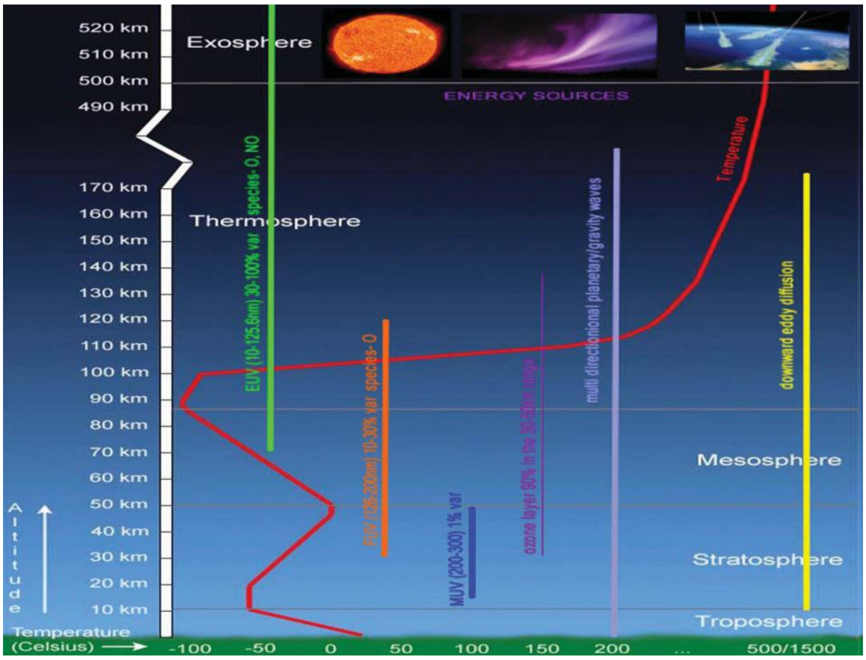

Figure 16. Shows sun-climate connection [9]

Figure 17. Shows the incidence of great earthquakes (magnitude 8 or more) since 1950, which is when reliable earthquake data began to be compiled. This is plotted against the sunspot activity as provided by the Solar Institute Data Centre.

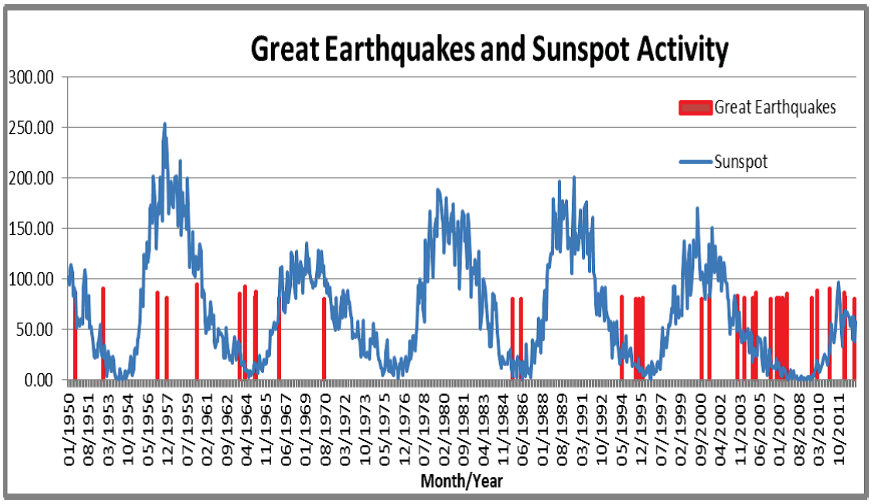

Figure 17. Frequency of Earthquakes and Sunspot Activity

The earthquake data should be very reliable since 1950 because it was around then that the US set up very sensitive measuring devices around the world. It is striking that of the 36 great earthquakes that have been recorded since 1950, 22 have been recorded since 1995 and 16 of them have been recorded since 2004, which is when the significant gravitational perturbation of the sun's plasma commenced. This suggests a six or sevenfold increase in frequency has resulted from that. However, if the theory explained in the Extra-terrestrial Influences on Nature's Risks paper contributes to the incidence of these then there should eventually be a slowdown in the frequency of these earthquakes. The reason why the incidence of great earthquakes is particularly altered is because they nearly always these occur on the boundaries of tectonic plates. Paradoxically, the frequency of lesser earthquakes on secondary fault lines should be high for some decades as the movements in tectonic plate boundaries will create stresses in subsidiary fault lines that could take many years, decades or even longer to be released [9].

The incidence of stratospheric volcanic eruptions is very limited. These are eruptions that emit large amounts of gases and particulates into the stratosphere. There were three large stratospheric volcanic eruptions during the Dalton Minimum and the records for earlier periods are very patchy. However, examination of ice core data suggests that during the Maunder Minimum there were a series of smaller stratospheric eruptions that seemed to have had the same effect as those in the Dalton Minimum. There were three known stratospheric volcanic eruptions in the 1980's: Mt St Helens, El Chichon and Mt Nevado. A higher incidence of volcanic eruptions is as a result of the higher levels of galactic cosmic rays and perhaps the one after have very weak sunspot activity, as NASA predicts.[9]

CONCLUSION

Understanding the solar cycle remains one of the biggest problems in solar physics. Although sunspots have been extensively studied for almost 400 years and their magnetic nature has been known since 1908, our understanding of a number of their basic properties is still evolving. Climate change on the planet is currently one of the most controversial debates among scientists and experts. Some experts believe that global warming is due to reasons of human activities, although the real causes of this phenomenon are not yet known. However, preliminary studies on this phenomenon have shown that global climate change is also connected to sunspots activity.

The aim of this study is to encourage researchers to understand the sunspot mechanism that have a direct impact on human life on the surface of the earth. Also to develop skills in space weather forecasting and in risk management activities that stem from such impacts. Such impacts can have the abilities to temporarily significantly change climatic conditions, earthquake and volcanic risks.

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