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STUDY OF SOME SOLAR ACTIVITIES AND THEIR EFFECTS ON SPACE TECHNOLOGY SYSTEMS

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ABSTRACT

Solar energetic particles (SEPs) and geomagnetic storms are the two primary space weather consequences of coronal mass ejections (CMEs) and their interplanetary counterparts (ICMEs). Space Weather effects on technology are manifold and can be experienced in deep space. Space weather effects are linked to the conditions in space environment, which largely are controlled by the Sun. Space weather can be described as the physical conditions in space that affects human technology in space such as radiation threat to crews of highflying aircraft and astronauts, high-frequency communication outages in the Polar Regions and so on. This review discusses the effects of space weather in brief.

Keywords: Solar energetic particles (SEPs), coronal mass ejections (CMEs).

1. INTRODUCTION

Within our own solar system, space weather is greatly influenced by the speed and density of the solar wind and the interplanetary magnetic field (IMF) carried by the solar wind plasma. A variety of physical phenomena are associated with space weather, including geomagnetic storms and substorms, energization of the Van Allen radiation belts, ionospheric disturbances and scintillation, aurora and geomagnetically induced currents at Earth's surface. Coronal Mass Ejections (CMEs) and their associated shock waves are also important drivers of space weather as they can compress the magnetosphere and trigger geomagnetic storms. Solar Energetic Particles (SEPs), accelerated by CMEs or solar flares, are also an important driver of space weather as they can damage electronics onboard spacecraft through induced electric currents, and threaten the life of astronauts.

Space weather exerts a profound influence in several areas related to space exploration and development. Changing geomagnetic conditions can induce changes in atmospheric density causing the rapid degradation of spacecraft altitude in Low Earth orbit. Geomagnetic storms due to increased solar activity can potentially blind sensors aboard spacecraft, or interfere with on-board electronics. An understanding of space environmental conditions is also important in designing shielding and life support systems for manned spacecraft. There is also some concern that geomagnetic storms may also expose conventional aircraft flying at high latitudes to increased amounts of radiation. For space weather research, the geomagnetic storm is of prime importance.

These space storms, like weather storms such as Hurricane Katrina in 2005, have caused severe damage to technological systems in the past. In March 1989, a large CME slammed into Earth causing massive power outages in eastern Canada.

1.1 SOLAR ENERGETIC PARTICLES (SEPS)

Solar energetic particles (SEPs) are so called because of their high energy, solar origin, and behavior as single particles. SEPs consist of electrons, protons, alpha particles, 3He nuclei and heavier ions up to Fe.

SEPs are observed as an increase in the particle flux as detected by a particle detector in space. Occasionally, protons penetrate Earth's atmosphere causing air showers and the resulting secondary neutrons are observed on the ground by neutron monitors. In fact the discovery of SEP events was made by Forbush (1946) in the neutron monitor records from 1942. These events are known as SEP events with ground level enhancement (GLE). Energetic particles are also observed with high intensities when IP shocks are intercepted by spacecraft.

1.2 PLASMAS

Space plasma are encountered in interplanetary space in the forms of solar wind continuously emanating from the sun, and in different parts of the magnetosphere and the ionosphere originating from various sources . The solar wind flows out with a speed of 400 km/s, corresponding to a kinetic energy of just below 1Kev for protons and has an average density of 5cm^{-3} at 1 AU. Both the speed and the density are variable, with a 5-95% range of cumulative probability of occurrence of 320 – 720 km/s and 3-20 cm^{-3} , respectively (ECSS, 2000). The two type solar wind from the equatorial regions of the Sun and the fast solar wind originating from coronal holes, usually located in the polar regions of the sun. The solar wind consists mainly of protons (95% of positively charged particles) with a

small portion of doubly - ionized helium and a trace of heavier ions. Electrons are also present in sufficient numbers to make the wind neutral. The effects of solar wind on technologies on ground and even in near – Earth space are indirect, caused by complex interactions of the solar wind and the coupled magnetosphere – ionosphere - atmosphere system. The ionosphere - magnetosphere system contains various plasma regimes. At the height of few hundred kilometers (at Low Earth Orbit) the plasma is cold (~1000 k or 0.1 eV) but high density (10^3 – 10^5 cm^{-3}). In the plasmasphere an extension of the ionosphere forming the inner part of the magnetosphere up to a few earth radii, the plasma density is typically 10 – 1000 cm^{-3} and the mean kinetic energy of the order of1 eV. At the plasma pause, the density drops suddenly, typically to 1 cm^{-3} at geostationary orbit (6.6 earth radii), while the energies are high, typically in the keV range.

1.3. MAGNETIC FIELDS

The solar wind carries with it a magnetic field of about 5nT that lies, due to solar rotation, near the ecliptic plane in an Archimedean spiral pattern. It has a wavy structure, which leads to a current sheet separated sector structure with the magnetic field direction alternately towards and away from the sun. During nominal interplanetary conditions, the interplanetary magnetic field (IMF) has no consequences on technological system in space, but during disturbed periods, when both the direction and strength of the IMF are highly variable, it is the most important parameter affecting the geomagnetic activity together with the velocity and density of the solar wind.

Earth’s magnetic field is basically a dipole field, but is strongly distorted by the magnetized plasma of the solar wind, leading to the structure known as the magnetosphere (Otto, 2004). On the dayside, during nominal solar wind conditions, the boundary of the magnetosphere is at the distance of 10 R_E, while on the night side it extends to hundreds of R_E. The inclination of the dipole field is about 11^o with respect of the earth's rotation axis and the offset from the centre of the earth in the year 2000 epoch was 540 km. The geomagnetic field is significant for space weather effects from several respects. It controls the near - Earth plasma environment. The geomagnetic field traps the particles in the radiation belts and controls their motion. The tilt of the dipole field with respect to the earth's rotation axis and the offset from the centre result in the South Atlantic anomaly, a region where high intensity radiation reaches exceptionally low latitudes due to the low magnetic field strength.

1.4 SOLAR ELECTROMAGNETIC RADIATION

The sun emits electromagnetic radiation at all wavelengths from gamma-rays to radio waves. The shape of the spectral distribution is such that the bulk of the solar energy lies between 150 nm and 10 µm with the maximum near 450 nm, *i.e.*, at the visible range of the wave lengths. However, the ultraviolet portion (< 300 nm) of the spectrum is the most important is determining the effects of solar radiations on the upper atmosphere and on technological systems in space. During solar storm conditions, also X-ray fluxes are significant. The variability of electromagnetic radiation in the visible wavelength range is very small over the solar cycle. Other part of the spectrum can be much more variable both over the 27-day solar rotation period and over the 11-years solar cycle. For the ultraviolet part, the variability can be of the order of factor 2, and can reach orders of magnitude for flare X-rays.

1.5 HIGH SPEED SOLAR WIND STREAMS

High speed solar wind streams emanating from coronal holes can drive interplanetary shocks and create intensive magnetic fields when interacting with streams of lower speeds. During low solar activity, coronal holes can be relatively stable, lasting for months and reach low solar latitudes. Therefore, at solar minimum, the high-speed solar wind streams are the dominating source of geomagnetic storms, described in the next section. They together with rotation cause recurrent storms with a 27-day pattern.

2. STORMS

Magnetic storms are come in the category of natural phenomena which have been known form hundreds of years. In recent times researchers have taken keen interest in understanding of Sun-Earth connection events such as solar flares, CMEs and concomitant magnetic storms. Magnetic storm is one of the important components of space weather effects on Earth. The formation of the ring current in the inner magnetosphere proved to be the main consequence of the magnetic storms. A geomagnetic storm includes three phases namely; **initial phase** (when there is an increase of the middle-latitude horizontal intensity (H) at the surface of the Earth), **main phase** (when the horizontal magnetic field at middle latitudes is generally decreasing, owing to the effects of an increasing westward flowing magnetospheric ring current) and **recovery phase** (when the depressed northward field component returns to normal levels (Lakhina et al., 2005 and Rostoker, 1997)).

The number of storms varies throughout the solar cycle, but typically is on the order of a few per month, with a great number and intensity of storms during solar maximum. Associated with every storm is a rapid brightening and expansion of the entire auroral oval in both the northern and southern hemispheres. In many storms, the radiation belts intensify and the inner edge of the outer radiation belt moves earthward. In some major storms, the slot region can be completely filled and the inner belt can intensify dramatically. However, adverse space weather effects, such as the disruption of communication, navigation, and power grid, occur at times of severe geo-magnetic storms, which are triggered by extreme solar wind conditions associated with explosive solar events (e.g., Earth-directed CMEs).

3. EFFECTS OF SOLAR EMISSIONS ON SPACE BASED TECHNOLOGICAL SYSTEMS

Space weather has broad impacts on humans lives and technology. Spacecraft and astronauts are directly exposed to intense radiation that can damage or disable systems and sicken or kill astronauts. Space weather storms modify the density distribution of the ionosphere. Because **radio wave propagation** depends on the medium the waves move through, a time variable and spatially inhomogeneous ionosphere can severely perturb and degrade ground-to-satellite and satellite-to-ground communication. This can have serious impacts on different systems, but is particularly important for high frequency (HF) radio communication and Global Positioning System (GPS) navigation systems.

3.1 HAZARDS TO HUMANS IN SPACE

Energetic solar protons are a radiation health hazards for astronauts on manned space flights. The arrival time in the near Earth environment can begin within tens of minutes of eruption of a solar flare. While low inclination orbits take advantage of the shielding of the Earth’s magnetic field, high inclination orbits place the shuttle outside normal rigidity cut-offs, allowing increased dosages. The radiation effects on human beings are same similar to the effects on electronics (Mcnully, 1996). The radiation exposure to passengers in high-altitude aircraft is also of concern. Although the residual atmosphere above an aircraft provides a measure of protection from cosmic rays and solar energetic particles that enter the magnetosphere, there is still concern for flights on polar routes during major solar particle events. Radiation sensors on Concorde supersonic jets showed that passengers and crew sometimes received a radiation dose equivalent to chest X-ray (Allen and Wilkinson, 1993).

Dose effects affect all cells, especially those, which are not renewed or at least not rapidly renewed. Single energetic particles can also break the DNA chain in the cell nucleus, producing chromosome aberrations, translocations and tumour induction. They can induce also cell mutation that can have effects on the genetics (Lemaignen, 1988; Koskinen et al., 2001). Space radiation has energies of many MeV and even GeV, whereas radioactivity is limited to energies of a few MeV (i.e. nuclear binding energies).

3.2 EFFECTS ON SATELLITES

Space weather affects satellite missions in a variety of ways, depending on the orbit and satellite function. Our society depends on satellite for weather information, communication, navigation, exploration, search and rescue, research and defense system. The impact of satellite system failure is more far-reaching than ever before, and the trend will almost certainly continue at an increasing rate. The satellites are in a variety of orbits, which means that each satellite has a unique path around Earth. Some satellites orbit close to Earth, others far from the surface. The orbit depends on the purpose of the satellite. There are four main important classes of orbits for Earth-orbiting satellites. The altitude above Earth that a satellite reaches defines the four main classes. These are low-Earth orbit (LEO), medium-Earth orbit (MEO), high-Earth orbit (HEO), and geosynchronous orbit (GEO).

The great storm of March 1989 caused thousands of space objects (including hundreds of operational satellites) to lose many kilometers of altitude. One satellite lost over 30 km of altitude during this storm. The atmospheric orbital decay process has been extensively studied since it is one of the main parameters affecting satellite lifetime, and large satellites in uncontrolled re-entry could crash into populated areas. Most satellites are small enough that they will completely burn up in the atmosphere and not reach the ground. However, pieces from large satellites (like fragments from Skylab that fell to Earth in July, 1979) can survive re-entry and reach the ground. This would be similar to a large meteor entering Earth's atmosphere, and depending on the size of the fragment, could have tragic consequences if it hit an urban area. Large satellites are designed with propulsion capabilities so that their re-entries are controlled. Many do enter Earth's atmosphere and have pieces reach the surface, but by careful maneuvering at the end of the satellite's lifetime, the fragments are dumped into the ocean away from population centers. The failure of the Japanese geostationary telecommunications satellite CS-3b (in 1989) and On 20-21 January 1994, three Canadian communication satellites suffered operational anomalies affecting television, radio, telephone and scientific operations, ranging from hours to days (Baker et al., 1994), and highlighted that many tens of billions of dollars are invested in satellite systems that are potentially at risk. More than 500 commercial and military satellites are estimated to be in geosynchronous orbit from various worldwide sources. Assuming that each may cost of the order of 200 million USD, this adds up to over 40 billion USD in hardware in geosynchronous orbit alone. Commercial communications satellites provide global news TV coverage, telephone connections, and credit card transactions. Governments operate many other satellites to provide weather images, navigational signals, land use information, and military surveillance. All are susceptible to damage and degradation due to the harsh space environment.

3.3 RADIO COMMUNICATION

The ionosphere affects the propagation of radio signals in different ways depending on their frequencies. Frequencies below ~50 MHz are reflected in the ionosphere; this allows radio communication to distances of many thousands of kilometers. Radio signals at frequencies above 50 MHz penetrate the ionosphere and are useful for ground-to-space communications. High-frequency (HF) radio is used for ship-to-shore and ship-to-ship communication as well as by commercial airlines for air-to-ground and ground-to-air communication. This radio band is also popular with amateur radio operators. HF radio frequencies are between 3 and 30 MHz. The ionosphere can reflect these frequencies, and therefore long-range communication is possible by bouncing your signal off the ionosphere several hundred kilometers above Earth. This phenomenon, called “skywave”, allows for over-the-horizon communication.

The benefit of this frequency band – that it can interact with the ionosphere to permit long-range radio communication – is also its problem. Because the ionosphere is highly variable in space and time, HF radio communication can be severely degraded or even made inoperable depending on a wide variety of factors. Many of these factors are related to space weather and include the amount of solar activity (and hence sunspot cycle) and geomagnetic activity (particularly aurorae). HF radio propagation depends on ionospheric density, which is controlled by sunlight and geomagnetic activity. Space weather degradation of HF radio has a particularly big impact on trans-polar airline flights.

During large geomagnetic storms, HF radio communication can be rendered inoperable over the poles. Therefore, commercial airlines, which rely on HF radio communication, must base their flight schedules on space weather forecasts. Airlines will re-route trans-polar flights during large geomagnetic storms because of the impact on their HF radio communication ability. Because of potentially serious impacts on HF radio communication, many users are switching to satellite phone communication (which uses much higher-frequency radio waves) and using HF as a backup system. However, since the cost of satellite communication is still relatively high, a significant number of industrial and government (maritime, aviation, and military) employees use HF radios, which are subject to space weather impacts.

3.4 GPS SATELLITE ERRORS

Modern travel requires exact latitude, longitude and altitude information in real time. Therefore terrestrial based radio wave systems such as the Loran-C and the Omega-system were developed. They use large transmitter antennas to send low-frequency (LF) and very-low-frequency (VLF) radio signals along the ground and off the reflective layer provided by the ionosphere. Thus, vast distances over land and sea can be reached. More recently, space-based systems have become the tools for navigation, among others the GPS system (Global Positioning System). The advantage of space-based systems is that the satellites can easily cover the globe. A user can obtain an accurate three dimensional position (his location and altitude) as soon as at least four satellites are in view. However both navigational systems, space-systems as well as systems on the surface suffer from the transmission through the ionosphere. The GPS operations are affected by the total electron content of the ionosphere along the path to the satellite and are thus influenced by geomagnetic storms.

The Global Positioning System (GPS) allows users to accurately locate their position on Earth. The system consists of over 28 satellites in medium-Earth orbit arranged in such a way that at any given point on Earth at least four satellites are in view of an observer with an unobstructed view of the sky. These satellites have atomic clocks on board and continuously broadcast the time. A user on the ground with a GPS receiver can get this signal. By comparing the time broadcast by the satellite with the time at which the signal arrived, a distance (distance equals speed of radio signal divided by time for the signal to go from satellite to ground-user) to the satellite can be estimated. By triangulation (the process of determining the position of an object using three independent distance determinations), the exact location of the user can be estimated. Because the user does not have an atomic clock, a fourth satellite is used to acquire accurate time and the three other satellites are used to triangulate position. The speed at which a radio signal propagates through a vacuum is the speed of light. However, the speed at which an electromagnetic signal like a radio wave propagates through matter is less than the speed of light. This is called diffraction and has the effect of slowing down and bending the signal. The amount of bending and how much slowing occurs depend on the frequency of the signal and the properties of the medium. For plasma, the property that determines electromagnetic propagation effects is the density. Therefore, because of ionospheric density, the radio signal from a GPS is slowed down. GPS systems attempt to account for this delay by using estimates or models of ionospheric density. So losses of phase lock and range errors in GPS are its main problems.

3.5 AURORA

Auroras, sometimes called the **northern and southern (polar) lights** or **aurorae**, are natural light displays in the sky, usually observed at night, particularly in the Polar Regions. They typically occur in the ionosphere. They are also referred to as **polar auroras**. Aurorae seen near the magnetic pole may be high overhead, but from further away, they illuminate the northern horizon as a greenish glow or sometimes a faint red, as if the sun was rising from an unusual direction. The aurora borealis most often occurs from September to October and from March to April. The northern lights have had a number of names throughout history. The Cree people call this phenomenon the "**Dance of the Spirits**." Aurorae can be spotted throughout the world. It is most visible closer to the poles due to the longer periods of darkness and the magnetic field. The phenomenon of aurora is an interaction between the Earth's magnetic field and solar wind.

4. DISCUSSION

In this review author try to elaborate the effect of space weather on space based technological systems. Our study shows how solar activities effect the space environment. To minimize the space weather effects we will have to develop an efficient mechanism or tool to early predict geomagnetic storms or other solar activities. A possibility of forecasting of solar activities or geomagnetic storms can help to avoid the expenditure on making of control measurements required during the high probability of disturbances.

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