International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Impact of Solar and Interplanetary Disturbances on Space Weather

S. K. Pandey[1], S. C. Dubey[2]
[1]Department of Physics, Rewa Engineering College, Rewa (M.P.), India-486002
[2]Department of Physics, S.G.S. Govt. P.G. College, Sidhi (M.P.), India-486661

***Abstract*— *Solar activity is the dynamic energy source behind all solar phenomena driving space weather. During an active solar period, violent eruptions occur more often on the Sun. The solar flares (SFs) and coronal mass ejections (CMEs) shoot energetic and highly charged particles towards Earth that ensuing ionospheric and geomagnetic disturbances. The some geomagnetic disturbances illuminate night skies with brilliant sheets of red and green known as auroras or northern and southern lights. All these phenomena are most frequent near the maximum of each 11-year cycle of solar activity. The Maunder minimum (1645-1715) refers to a period when very few sunspots were observed. During this period, the Earth climate was cooler than normal. This period mimics the solar cycle climate change connections. The particles and electromagnetic radiations flowing from solar activity outbursts are important for long-term climate variations.*

The geomagnetosphere and upper atmosphere can be greatly perturbed by variations in the solar wind caused by disturbances on the Sun. In recent years, these in situ data have resulted in explosive growth in our knowledge and understanding of solar-interplanetary-terrestrial process. The magnetic reconnection provides opportunity to enter solar plasma within geomagnetosphere. Two kinds of flows dominate the large scale structure of solar wind: corotating flows and transient disturbances. Corotating flows are associated with spatial variability in coronal expansion and solar rotation, whereas transient disturbances are associated with episodic ejections of material into interplanetary space from coronal regions. There are two types of geomagnetic field variations termed as long-time variation and storm-time variations. The long-term variations are very useful to solar cyclical study of geomagnetic field variation as well as change in polarity of the Sun, climate change, plants growth rate and geological change of Earth's pole. The storm-time variations deal the various characteristics of geomagnetic storms (GMSs) and their connection with solar source activities and interplanetary magnetic fields.

Keywords*— *CMEs, SRF, SFI, D_{st}, Geomagnetosphere.

I. INTRODUCTION

Geomagnetic activities have long been known to be correlated with solar activities and representative by various geomagnetic indices. The Dst index is an index of geomagnetic activity derived from a network of near-equatorial geomagnetic observatories that measures the ring current intensity of the globally symmetrical equatorial electrojet. The Dst index has been introduce by (Sugiura, 1964) and used for solar quiet daily variation. The average behaviours of the geomagnetic field disturbances on mid-latitude are available through measurements of planetary Kp and Ap indices. The values of Kp index are available on 3-hour interval logarithmic scale, whereas planetary index Ap represents the degree of global geomagnetic variability of each day. The substorm indices AU, AL, AE and AO are also known as Auroral Electrojet or high latitude indices. These indices were introduced by Davis and Sugiura (1966) for a measure of the strength of auroral electrojets relatively dominated by effects of the ring current. The index AE is designed to provide a global, quantitative measure of auroral zone magnetic activity produced by enhanced ionospheric current flowing along the margin of the auroral oval. Geomagnetic index aa are useful datasets which indicate solar activity levels. The geomagnetic aa index is largely used for solar cycle prediction in the so called precursor methods, which are currently the most successful and are believed to be correlated with the solar dynamo mechanism. The PC-index has been introduced by Troshichev et al (1979) as an index for monitoring geomagnetic activity over the polar caps caused by changes in the interplanetary magnetic field (IMF) and solar wind. The PC-index is a fifteen-minute and one-minute index for geomagnetic activity in the Polar Cap.

The Sun is continuously ejecting large quantities of charged particles into space. Some of these particles eventually arrive at the Earth and interact with the Earth's magnetic field. The amount of charged particles ejected by the Sun varies from day to day and also with the 11-year sunspot cycle. For the last hundred years or more, the primary index of solar activity has been the Wolf (Zürich) sunspot number R_z, available since 1700. The solar flare index (SFI) is of value as a measure of this short-lived activity on the Sun was introduced by Kleczek (1952). In recent years, many other solar indices were established (notably the 2800 MH_z, 10.7 cm radio emission flux, denoted as $\boldsymbol{F_{10.7}}$, recorded routinely by a radio telescope near Ottawa since 14th February 1947, presently operated by the National Research Council using two fully automated radio telescopes at the Dominion Radio Astrophysical Observatory, Penticton, Canada). Solar flux provides a good first order approximation for the F-region that is responsible for most long distance ionospheric radio communications propagation. The solar energetic particle (SEP) events are the energetic outbursts as a result of acceleration and heating of solar plasma during solar flares and CMEs. All these activities show an 11-year cycle, except that during sunspot minimum when sunspot numbers almost reach zero, most of the other indices reach a minimum nonzero level. Solar activity indices show variations in a wide range of time scales, from a few days to several years. In short-term variations, the most prominent is the 27-day periodicity, which is attributed to the solar rotation of sunspot groups.

The strength of interplanetary magnetic field and its fluctuations have been shown to be most important parameters affecting the geomagnetic field variations. The north-south component of IMF B_z plays a crucial role in determining the amount of solar wind energy to be transferred to the Earth's magnetospheres (Arnoldy, 1971; Tsurutani and Meng, 1972; Russell and McPherron, 1973; Akasofu, 1981). The mechanism of transferred solar wind energy into the Earth's magnetosphere depends upon magnetic reconnection between IMF and Earth's magnetic field. When the IMF B has large magnitude and a large southward component IMF B_z, the amount of transferred solar wind energy becomes very large, which causes intense geomagnetic disturbances. Conversely, when IMF B_z is directed primarily northward, the transferred energy becomes very small and produces small geomagnetic disturbances. During the solar maximum, the presence of active regions provides an opportunity to increase IMF B magnitude and large southward component, resulting in a large number of intense geomagnetic disturbances. Conversely, small and fewer numbers of geomagnetic disturbances are observed during solar minimum due to solar rotation and presence of coronal holes.

II. Data Technique

Geomagnetic field variations measured by instruments on the ground and in space provide information about the solar wind and the Earth's magnetic field. The superposition of the effects of a variety of different current systems causes these geomagnetic fields. The processes that produce these currents are the subject of interest to space physicists. A number of different instruments have been developed to measure these geomagnetic fields. These instruments were based upon variations of the compass, more recent, such instruments have been replaced with more sophisticated devices based on the other principles, including magnetic hysteresis, proton precession, and the Zeeman Effect. Magnetic observatories have recorded data for well over 100 years. Their magnetograms or photographed on microfilm are submitted to World Data Centers, where they are available for scientific or practical uses. The level of the geomagnetic activity is measured using different magnetic activity indices, most of which are based on ground-based magnetometer recordings. These recordings can be used for the study the longer trends in the solar activity.

III. Space Weather and its Effect

Space weather is the concept of changing environmental conditions in near-Earth space or the space from the Sun's atmosphere to the Earth's atmosphere. It is distinct from the concept of weather within the Earth's planetary atmosphere. Space weather is the description of changes in the ambient plasma, magnetic fields, radiation and other matter in space. Much of space weather is driven by energy carried through interplanetary space by the solar wind from regions near the surface of the Sun and the Sun's atmosphere (chromosphere and corona). Within our own solar system, space weather is greatly influenced by the speed and density of the solar wind and the 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 of satellite-to-ground radio signals and long-range radar signals, aurora and geomagnetically induced currents at Earth's surface. 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, accelerated by CMEs or SFs, are also an important driver of space weather as they can damage electronics onboard spacecraft, and threaten the life of astronauts.

The space weather (SWx) effects are related to different solar phenomena each of which produces a different mix of enhanced emission. Some solar events cause little or no impact on the near-Earth environment either because their enhanced electromagnetic and/or particle emissions are too feeble, or because their particle streams may simply miss the Earth. For those events that do affect the near-Earth environment, effects can be both immediate and delayed, depending on the exact type of enhanced emission.

Immediate effects are caused by enhanced electromagnetic radiation – i.e. γ-ray, X-ray, ultraviolet, optical and radio waves. Since all type of radiation travel at the speed of light, the time taken for them to reach the Earth is the same. So, by the time a flare is first observed it is already causing immediate effects on the near-Earth environment. As the radiation does not penetrate or bend around the Earth, the impacts are almost entirely limited to the Earth's sunlit hemisphere. Because the enhanced emissions cease when the flare ends, the effects tend to subside as well; as a result, effects caused by enhanced electromagnetic radiation tend to last only a few tens of minutes to an hour.

Delayed effects are caused by particles. High-energy particles can reach the Earth within 15 minutes to a few hours after the occurrence of a strong SF. Not all flares produce such particles and since the particles follow trajectories defined by the spiralling interplanetary magnetic field, they may miss the Earth. The major impact of the particles is felt over the polar caps, where the protons have ready access to low altitudes through funnel-like cusps in the Earth's magnetosphere. Proton events are possibly the most hazardous of space weather events; their impact can continue for a few hours to several days after the SF. Streams of plasma, in the form of medium and low-energy particles, may arrive at the Earth about two to three days after a flare, but can also occur at any time due to non-flare solar activity such as CHs, and CMEs. The particles may cause geomagnetic and ionospheric storms that can last from hours to several days; the impacts these cause are most intense in the night-side sector of the Earth.

A. *Effect of Space Weather on Space Systems*

Spacecraft Anomalies- Spacecraft malfunction for a variety of reasons. Radiation passes through the skin of the spacecraft and into the electronic components. In most cases the radiation causes an erroneous signal or changes one bit in memory of a spacecraft's electronics (single event upsets). In a few cases, the radiation destroys a section of the electronics (single event latchup). Spacecraft charging is the accumulation of an electrostatic charge on a non-conducting material on the spacecraft's surface by low energy particles. If enough charge is built-up, a discharge (spark) occurs. Damage to the spacecraft is done by causing an erroneous signal to be detected and acted on by the spacecraft computer as if the signal came from the ground controller or the electronics are damaged by a surge of electrical current. A recent study indicates that spacecraft charging is the predominant space weather effect on spacecraft in geosynchronous orbit.

Spacecraft Orbit Changes- The orbits of spacecraft in low Earth orbit (LEO) decay to lower and lower altitudes due to the resistance from the friction between the spacecraft's surface (i.e., drag) and the outer layer of the Earth's atmosphere (the thermosphere and exosphere). Eventually, a spacecraft's orbit will decay so much that it will fall out of orbit and crash to the Earth's surface.

Effect of Radiation on Humans in Space- The exposure of a human body to ionizing radiation has the same harmful effects whether the source of the radiation is a medical X-ray machine, a nuclear power plant or radiation in space. The degree of the harmful effect depends on the length of exposure and the energy density of the radiation. The ever-present radiation belts extend down to the altitude of manned spacecraft such as the International Space Station (ISS) and the Space Shuttle but the amount of exposure is within the lifetime exposure limit under normal conditions. During a major space weather event which includes a burst of solar energetic particles, the flux can increase by one to several orders of magnitude. There are areas within ISS where the thickness of the spacecraft surface and equipment can provide extra shielding and may keep the total dose absorbed within lifetime safe limits.

B. *Effects of Space Weather on Ground Systems*

Disruption of GPS and other Spacecraft Signals- The ionosphere bends radio waves in the same manner that water in a swimming pool bends visible light. When the medium through which the light or radio waves travel is disturbed, the light image or radio information is distorted and can become unrecognizable. The degree of distortion (scintillation) of a radio wave by the ionosphere depends on the frequency of the radio signal. Radio signals in the VHF band (30 to 300 MHz) can be distorted beyond recognition by a disturbed ionosphere. Radio signals in the UHF band (300 MHz to 3 GHz) will propagate through a disturbed ionosphere but a receiver may not be able to keep locked to the carrier frequency. The Global Positioning System uses signals at 1575.42 MHz (L1) and 1227.6 MHz (L2) which can be distorted by a disturbed ionosphere and a receiver computes an erroneous position or fails to compute any position. Because the GPS signals are used by wide range of applications, any space weather event which makes GPS signal unreliable, the impact on society can be significant.

Disruption of Long-Distance Radio Signals- Radio wave in the HF band (3 to 30 MHz) are bent so much by the ionosphere that they are reflected back in the same manner as a mirror reflects light. Since the ground also reflects HF wave, a signal can be transmitted around the curvature of the Earth to a distant station. During the 20th century, HF communications was the only method for a ship or aircraft far from land or a base station to communicate. With the advent of systems such as Iridium, there are now other methods of communications but HF is still considered to be critical because not all vessels carry the newer equipment and even if the newer equipment is onboard, HF is considered a critical backup system. Space weather events can create irregularities in the ionosphere that scatter HF signals instead of reflecting them and make HF communications over long distance poor or impossible. At auroral and polar latitudes, small space weather events which occur frequently disrupt HF communications. At mid-latitudes, HF communications are disrupted by solar radio bursts, by X-rays from solar flares (which enhance and disturb the ionospheric D-layer) and by TEC enhancements and irregularities during major geomagnetic storms which are infrequent.

Effect of Radiation on Humans at and near Ground Level- The Earth's magnetic field guides cosmic ray and SEPs to polar latitudes and radiation particles enter the mesosphere and stratosphere. Cosmic rays at the top of the atmosphere shatter atmospheric atoms and create lower energy, but still harmful, radiation particles which penetrate deep into the atmosphere. All aircraft flying above 10 km altitude are exposed to a noticeable amount of radiation. The exposure is greater in polar regions than at mid-latitude and equatorial regions. Many commercial aircraft from Europe and North America to East Asia fly over the polar region. When a space weather event causes radiation exposure to exceed the safe level set by aviation authorities, the aircraft's flight path is deviated to avoid the polar region.

Ground Induced Current: Electrical Transmission, Pipelines, etc- A well-known ground-level consequence of space weather is geomagnetically induced current, or ground induced current or GIC. GIC flows through the ground to depths of 20 km or more during geomagnetic storms. A well-known example of the adverse effect of a GIC event is the collapse of the Hydro-Québec power network on 13th March 1989. This was started by a failure of an overloaded transformer, which led to a general blackout, which lasted more than 9 hours and affected 6 million people. GICs enter power grids, pipelines and other conducting networks through grounding wires. Pipelines and other activities at high latitudes are affected by GIC driven by modest levels of auroral activity which occur almost daily. GICs associated with space weather can affect other systems such as geophysical mapping and hydrocarbon production.

Geophysical Exploration- Air and ship borne magnetic surveys can be affected by rapid magnetic field variations during geomagnetic storms. Geomagnetic storms cause data interpretation problems because the space-weather-related magnetic field changes are similar in magnitude to those of the sub-surface crustal magnetic field in the survey area. Accurate geomagnetic storm warnings, including an assessment of the magnitude and duration of the storm, allows for an economic use of survey equipment.

C. Observations of Space Weather

The observation of space weather is done both for scientific research and for applications. The type of observation done for science has varied over the years as the frontiers of our understanding has increased and due to competition for resources from other types of space-related research. The observations related to applications have been more systematic and has expanded over the years as awareness and applications have increased.

Observing Space Weather from the Ground- Presently, space weather is monitored at ground level by observing changes in the Earth's magnetic field over periods of seconds to days, by observing the surface of the Sun and by observing radio noise created in the Sun's atmosphere. The sunspots are on the Sun's photosphere in visible light on the side of the Sun visible to an Earth observer. The number and total area of SSN are related to the brightness of the Sun in the EUV and X-ray portions of the solar spectrum and to solar activity such as solar flares and CMEs. 10.7 cm radio flux is a measurement of RF emissions from the Sun and is approximately correlated with the solar EUV flux. Radio noise burst are associated with plasma from a solar flare interacting with the ambient solar atmosphere. Total Electron Content (TEC) is a measure of the ionosphere over a given location. TEC is the number of electrons in a column one meter square from the base of the ionosphere to the top of the ionosphere. Many of the measurements of TEC are made by monitoring the two frequencies transmitted by GPS spacecraft.

Dst index is an estimate of the magnetic field change at the Earth's magnetic equator due to a ring of electrical current at and just earthward of GEO. Kp and Ap Index measure the geomagnetic disturbance at one mid-latitude. The AE index is made public with a delay of two to three days, which severely limits its utility for space weather applications. The AE index indicates the intensity of geomagnetic substorms except during a major geomagnetic storm when the auroral zones expand equatorward from the observatories.

The Sun's photosphere is observed continuously by a series of observatories for activity which can be the precursors to solar flares and CMEs. The Global Oscillation Network Group (GONG) project monitors both the surface and the interior of the Sun by using helioseismology, the study of sound waves propagating through the Sun and observed as ripples on the solar surface. GONG can detect sunspot groups on the far side of the Sun.

Neutron Monitors on the ground indirectly monitor cosmic rays from the Sun and galactic sources. Cosmic rays do not reach the Earth's surface due to the shielding of the Earth's magnetic field and atmosphere. When cosmic rays interact with the atmosphere, atomic interactions occur which cause a shower of lower energy particles to descend deeper into the atmosphere and to ground level. The presence of cosmic rays in the near-Earth space environment can be detected by monitoring high energy neutrons at ground level. Small fluxes of cosmic rays are present continuously. Large fluxes are produced by the Sun during events related to energetic solar flares.

Observing Space Weather with Satellites- Many of the earliest spacecrafts are used for monitoring the space environment. The first of these is the IMP-8 (Interplanetary Monitoring Platform). The IMP-8 orbited the Earth at 35 RE and observed the solar wind for two-thirds of its 12-day orbit from 1973 to 2006. Since the solar wind carries disturbances which affect the magnetosphere and ionosphere, IMP-8 demonstrated the utility of continuously monitoring the solar wind. IMP-8 was followed by ISEE-3 which was placed near the L1 Sun-Earth Lagrangian point, 235 RE above the surface and continuously monitored the solar wind from 1978 to 1982. The next spacecraft to monitor the solar wind at the L1 point was WIND from 1994 to 1998. After April 1998, the WIND spacecraft orbit was change to circle the Earth and pass by the L1 point occasionally. The NASA -ACE has monitored the solar wind at the L1 point from 1997 to present. In addition to monitoring the solar wind, monitoring the Sun is important to space weather. Because the solar EUV cannot be monitored from the ground, SOHO spacecraft was launched and has provide EUV images of the Sun from 1995 to the present. SOHO is a main source of near-real time solar data for both research and space weather prediction. The Yohkoh spacecraft at LEO observed the Sun from 1991 to 2001 in the X-ray portion of the solar spectrum and was useful for both research and space weather prediction.

IV. CLIMATE CHANGE

Climate change holds the significant changes in physical and biological systems in all the continents and oceans. It also threatens to destabilize natural phenomena on a regional as well as global scale; some warning signs are already visible. Unprecedented occurrence of severe droughts, heat waves, storms, heavy precipitation, floods, cyclones, shifts in climate zones and seasonality, and increase in sea level and temperature have been reported from various regions of the globe. As these ill effects intensify, they will increasingly cause stress to our ecosystems and tribulations to the livelihood and resources of islands, beaches and coasts. The deterioration of the Earth's ecosystems will jeopardize human health; precipitation patterns; water and food supplies; energy supplies; and the integrity of natural systems.

The basic components that influence the Earth's climatic system can occur externally (from extraterrestrial systems) and internally (from ocean, atmosphere and land systems). The external change may involve a variation in the Sun's output. Internal variations in the Earth's climatic system may be caused by changes in the concentrations of atmospheric gases, mountain building, volcanic activity, and changes in surface or atmospheric albedo. There is an abrupt and drastic cooling in the climate can be possible in near future due to large scale melting of global ice by global warming, and prolonged sunspot minima. There is a close correlation between variations in the 11-year sunspot cycle and Earth's climate. Solar activity varies on shorter-time scales, including the 11-year sunspot cycle and longer-term as Milankovitch cycle.

Variations in the Earth's Orbital Characteristics

The Milankovitch theory suggests that normal cyclical

S. K. Pandey and S. C. Dubey "Impact of solar and interplanetary disturbances on space weather," *International Research Journal of Advanced Engineering and Science*, Volume 2, Issue 1, pp. 125-130, 2017.

International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

variations in three of the Earth's orbital characteristics are probably responsible for some past climatic change. The basic idea behind this theory assumes that over time these three cyclic events vary the amount of solar radiation that is received on the Earth's surface. The first cyclical variation, known as eccentricity, controls the shape of the Earth's orbit around the Sun. The orbit gradually changes from being elliptical to being nearly circular and then back to elliptical in a period of about 100,000 years. The second cyclical variation results from the fact that, as the Earth rotates on its polar axis, it wobbles like a spinning top changing the orbital timing of the equinoxes and solstices. This effect is known as the precession of the equinox. The precession of the equinox has a cycle of approximately 26,000 years. The third cyclical variation is related to the changes in the tilt (obliquity) of the Earth's axis of rotation over a 41,000 year period. During the 41,000 year cycle the tilt can deviate from approximately 22.5 to 24.5°. At the present time, the tilt of the Earth's axis is 23.5°. When the tilt is small there is less climatic variation between the summer and winter seasons in the middle and high latitudes. Winters tend to be milder and summers cooler. Warmer winters allow for more snow to fall in the high latitude regions. When the atmosphere is warmer it has a greater ability to hold water vapor and therefore more snow is produced at areas of frontal or orographic uplift. Cooler summers cause snow and ice to accumulate on the Earth's surface because less of this frozen water is melted. Thus, the net effect of a smaller tilt would be more extensive formation of glaciers in the polar latitudes.

Volcanic Eruptions

Several major volcanic events also show a pattern of cooler global temperatures. The dust emitted into the atmosphere from large volcanic eruptions was responsible for the cooling by partially blocking the transmission of solar radiation to the Earth's surface. However, measurements indicate that most of the dust thrown in the atmosphere returned to the Earth's surface within six months. Recent stratospheric data suggests that large explosive volcanic eruptions also eject large quantities of sulfur dioxide gas which remains in the atmosphere for as long as three years. Atmospheric chemists have determined that the ejected sulfur dioxide gas reacts with water vapor commonly found in the stratosphere to form a dense optically bright haze layer that reduces the atmospheric transmission of some of the Sun's incoming radiation.

Variations in Solar Output

Changes in visible and infrared solar radiation alter the surface temperature by simple heating; other parts of the spectrum can also affect climate, through paths that are less direct. The enhanced UV radiation released from the Sun during high solar activity increases the amount of ozone in the stratosphere. At times of minima in the 11-year sunspot cycle, less ozone is found. One consequence of these solar perturbations is to complicate the detection of human-induced depletion of the protective ozone layer; another may be to perturb the temperature at the Earth's surface, through connections that link the upper and lower parts of the atmosphere. The Total Solar Irradiance (TSI) is integrated solar energy flux over the entire spectrum which arrives at the top of the atmosphere at the mean Sun-Earth distance. TSI has been monitored from 1978 by several satellites, e.g. Nimbus 7, Solar Maximum Mission (SMM), the NASA, Earth Radiation Budget Satellite (ERBS), NOAA9, NOAA 10, Eureca and the UARS (Upper Atmospheric Research Satellite) etc. The long-term solar irradiance variations might contribute to global warming over decades or hundreds of years. Sun has shown a slight cooling trend since 1960, over the same period that global temperatures have been warm. According to TSI variation trends in recent decades, the Sun has contributed a slight cooling influence but our globe is warmed up continuously. It is indication for a dangerous period and high awareness about global warming is most essential, otherwise we left our Earth as flame of burning for next generation.

The Carrington GMS Event of 1859

The most severe space weather event recorded in history is the Carrington Event of 1859. From 28th August to 4th September 1859, auroral displays, often called the northern or southern lights, spanned several continents and were observed around the world. A British amateur astronomer, Richard Carrington, recorded the solar outburst, a white-light SF, which was verified independently by Richard Hodgson in London. Across the world, telegraph networks experienced disruptions and outages as a result of the currents generated by the GMSs. In addition to disturbing the telegraph networks, operators in various locations disconnected batteries from their systems and used the current generated by the aurora to send messages (NAS, 2008). The economic costs associated with a catastrophic event similar to that of the Carrington Event could measure in the range of several trillion dollars (U.S. House Homeland Security Committee, 2009).

The 1989 Quebec Power Outage GMS Event

The GMS of March 1989 was the largest GMS of the decade and one of the largest of the century. It was occurred on 13th March 1989 with a Dst index of −599 nT. The planetary index Ap rose to 279 during this superstorm. This GMS was occurred just three months before the peak of solar cycle 22. The 13th March 1989 GMS was the result of a large and complex sunspot group identified as NOAA region 5395. This region produced 11 X-class and 48 M-class X-ray SFs during 6th to 19th March 1989. On 13th March 1989, a GMS affected Canadian and U.S. power systems, resulting in a major power outage for nine hours for the majority of the Quebec region and for parts of the northeastern United States (Molinski et al., 2000). The Hydro-Quebec grid's geographic location and its 1,000 km transmission lines to the load center made it susceptible to GMSs (Kappenman and Albertson, 1990). Central and southern Sweden also experienced power losses when GICs disrupted six 130kV power lines (Babayev et al., 2007). The GICs flowing through the power system severely damaged seven static compensators on the La Grande network in the Hydro-Quebec grid, causing them to trip or shut down automatically before preventive measures were

S. K. Pandey and S. C. Dubey "Impact of solar and interplanetary disturbances on space weather," *International Research Journal of Advanced Engineering and Science*, Volume 2, Issue 1, pp. 125-130, 2017.

possible (NERC, 1990). The loss of the compensators resulted in a system disturbance and severe equipment damage. The unavailability of new equipment to replace the La Grande network's damaged equipment prevented power restoration to the transmission network. The power delay was also due to the damaged equipment and load transfers at the distribution network level. While work was being conducted to bring power back to the Hydro-Quebec grid, the New Brunswick and Ontario power systems helped provide emergency assistance to Quebec. As power was restored to Hydro-Quebec, it received assistance from New England and New York systems as well as the Alcan and McLaren systems based in Quebec. The voluntary reduction of power use by industrial customers during the incident also helped Quebec to meet its power demands.

REFERENCES

[1] Akasofu, S. -I., 1981, Space Sci. Rev., 28, 121.
[2] Arnoldy, R., 1971, J. Geophys. Res., 76, 5189.
[3] Babayev, E.S. et al., 2007, Technological, Socio-Economic and Ecological Aspects of Space Weather Impacts on the Normal Operation of Oil and Gas Pipeline Systems and Reliability of Electric Power Supply Grids in Azerbaijan and the South Energy Corridor Region, Euro-Asian Journal of Sustainable Energy Development Policy, 2007.
[4] Dubey, S. C., 1998, Indian Journal of Radio and Space Phys., 27, 43.
[5] Dubey, S.C. and Mishra, A.P., 2000, Earth Moon and Planet, 84, 34.
[6] Gopalswamy, N. 2006, J. Astrophys. Astron., 27, 243.
[7] Gopalswamy, N., Yashiro, S. and Akiyama, S., 2007, J. Geophys. Res., 112, A06112.
[8] Kappenman, John G., et al., 1990, Solar Wind Monitor Satellite Crucial for Geomagnetic Storm Warning, IEEC Power Engineering Review.
[9] Kleczek, J., 1952, Publ. Inst. Centr. Astron., No. 22, Prague.
[10] Molinski, Tom S., et al., 2000, Shielding Grids from Solar Storms, IEEE Spectrum, November 2000.
[11] NAS, 2008, Severe Space Weather Events—Understanding Societal and Economic Impacts Workshop Report, National Academies Press, Washington, D.C.
[12] NERC, 1990, North American Electric Reliability Corporation, March 13, 1989 Geomagnetic Disturbance, NERC, Princeton, NJ.
[13] Russell, C. T. and McPherron, R. L., 1973, Space Sci. Rev., 15, 205.
[14] Sugiura, M., 1964, Ann. IGY, 35 (Part-I), 9-45.
[15] Troshichev, O. A., Dmitrieva, N. P. and Kuznetsov, B. M., 1979, Planet. Space Sci., 27, 217.
[16] Tsurutani, B. T. and Meng, C. I., 1972, J. Geophys. Res., 77, 2964.
[17] Wang, Y. M. and Sheeley, N. R., 2009, Astrophys. J., 694, L11–L15.
[18] Wang, R., 2007, Adv. Space Research, 40, 1835-1841.