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A STUDY FOR CAUSE OF GEOMAGNETIC STORM ON 13 MARCH, 1989 OF SOLAR CYCLE 22

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ABSTRACT

In this paper, we have studied the cause of geomagnetic storm on 13 March, 1989 of solar cycle 22. We conjectured that the solar variability is basic cause of geomagnetic storm. For our study we have utilized daily value of solar parameter (sunspot number, solar proton flux, solar flare class, frequency occurrence of solar flare) as well as geomagnetic disturbance indices (Ap, Kp, Dst) and cosmic ray intensity data from ground based neutron monitor of Moscow having magnetic cut-off rigidity 2.42 GV, latitude 55.47N and longitude 37.32E. We observed that a severe geomagnetic storm struck earth on March 13, 1989 observed by Lerner and Eric (1995) and CBC News (2005). It occurred during active phase of solar cycle 22 and gave a result that it disrupts human atmosphere and their communication system.

KEYWORDS: Solar cycle 22, solar flare, geomagnetic storm, cosmic ray

INTRODUCTION

A solar flare was first observed by Carrington and Hodgson (1859). A solar flare is sudden flash of brightness observed near the sun surface. It involves a very broad spectrum of emission requiring energy 6×10^{25} joules. X-ray and UV-radiation emitted by solar flare affect earth ionosphere and disrupt long radio emission at decimetre wavelength. The event of frequency occurrence of solar flares changes with sunspot number and CMEs variation and these flares have all frequencies of electromagnetic radiation.

On 23 July 2012 a massive and potentially damaging solar super storm (solar flare, coronal mass ejection and solar EMP) barely missed earth, according to NASA stated by Philips and Tony (2014). A coronal mass ejection (CME) is the massive bursts of gas (plasma) and magnetic field arising from solar corona and being released into solar wind. CME typically reach earth one to five days after leaving the sun. During their propagation CMEs and solar flare interact with the solar wind and interplanetary magnetic field (IMF).

A solar flare interact the solar wind resulting in a cause of solar proton event (SPE). When the halo CMEs and solar flare interacting with continuously coming cosmic ray toward the earth the result is decreased cosmic ray reach on to the surface of earth. Halo CMEs and solar flare are fundamental cause of the geomagnetic storm and aurora oval near to the earth. When the magnetospheric currents connect with aurora, result is increased geomagnetic storm (GMS). It means the auroras are also the cause of GMS. The big size Earth directed solar flare are sometimes associated by CMEs that can be cause of generation of geomagnetic storm which destroy several project launched by human.

The radiation problem of solar flares is related of a man made mission as like the Mars, the Moon or other planets. Energetic protons of solar flares can pass through the human body which produced biochemical damage. These flares are also created problem for astronauts during interplanetary travel for any purpose.

GEOMAGNETIC STORMS

During geomagnetic storms the magnetic field in the magnetosphere and on the ground is strongly disturbed globally. The perturbation of the magnetic field during a storm is due to the enhancement of the equatorial ring current. During storm time the ring current is enhanced and moved spatially closer to the ground. This causes a disturbance in the H component of the magnetic field.

It can be detected on the ground, as is indeed done at the multiple magnetic observatories. The storms are then classified according to some criteria, most often a specific index calculated from the magnetic measurements of a subset of the observatories. Being global events, the disturbance of the magnetic field during magnetic storms has to be detected by several stations at once to qualify. The most common index to classify the magnitude of the storm is the Dst index (Gonzalez et al., 1994). Since no magnetic storm is quite the same due to their complicated origins and dynamics the statistical approach used here has to be used with care (Koskinen, 2011), any conclusions ultimately requiring statistical significance analysis.

LITERATURE REVIEW

According to L. I. Dorman et al. (1993), the International Cosmic Ray Service (ICRS) main idea is to combine satellite and spaceprobe cosmic rays, magnetic and plasma data with groundbased cosmic ray data (exchanged in real time) to obtain continuous information on the electromagnetic and radiation situation in interplanetary space and Earth's magnetosphere: prediction of large geomagnetic storms, large increases in radiation hazards, and other dangerous phenomena in space.

In the estimated IMF polarity, Juckett (1998) discovered a 16.5-year and 9.1-year periodicity. Dvornikov and Sdobnov (1996) discovered a 5.5-year interval in numerous solar parameters. The periodicity of solar wind velocity, geomagnetic activity, and cosmic rays was also discovered to be 1-2 years. Active longitudes and a skewed dipole structure are connected with a 13.5-day period. This era may be seen in the solar wind speed, calcium K lines, plages, sunspot area and quantity, and solar magnetic field. It increases in chromospheric variables at solar maximum, solar wind, and the waning phase of solar activity. Most metrics linked with solar, interplanetary plasma, and geomagnetic activity display a quasi-periodicity of 14 days.

Neugebauer (1999) discovered this time in the IMF radial component of the geomagnetic field. The solar wind velocity and the interplanetary magnetic field have a substantial influence on geomagnetic activity (IMF).

Rajesh KUMAR Mishra (2008) utilised hourly averaged cosmic ray readings from the Moscow neutron monitor. The fluctuations in cosmic ray intensity data provided by neutron monitoring stations were compared to those in geomagnetic disturbance, solar wind velocity (V), interplanetary magnetic field (B), and their product (V' B) near the Earth from 1964 to 2004 in order to identify a probable association. The influence of the interplanetary medium's large-scale structure modulates galactic cosmic ray propagation in the heliosphere. During solar cycles 21 and 22, a substantial negative association was detected between the interplanetary magnetic field, product (V' B), and cosmic ray intensity. During solar cycle 21, the solar wind velocity has a strong positive association with cosmic ray intensity, but it has a modest link during cycles 20, 22, and 23. The interplanetary magnetic field has a weak negative correlation with cosmic rays during solar cycle 20, and a strong anti-correlation with cosmic ray intensity during solar cycles 21-23, which has a strong positive correlation with disturbance time index (Dst) during solar cycles 21 and 22, and a weak correlation during solar cycles 20 and 23.

Kalpana Singh (2008) investigates the solar and interplanetary disturbances that cause geomagnetic storms. Large perturbations in the earth's magnetic field are known as geomagnetic storms (GSs). 142 GSs (Dst -150nT) were chosen between 1996 and 2007. Isolated geomagnetic storms generally have a 3-12 hour primary phase and a 3 day recovery phase. Coronal mass ejections (CMEs) linked with radio bursts are significant solar phenomena that cause huge geomagnetic storms (Dst -50nT). During the specified time, 77 GSs (-100nT Dst -50nT), 50 GSs (-200nT Dst -100nT), and 15 events (Dst -200nT) of various magnitudes were discovered. The proportion of GSs linked with CMEs is ≈58%, the percentage of GSs associated with type II burst is ≈32%, the percentage of GSs associated with type IV burst is ≈12%, and the percentage of GSs related with brilliant flare is ≈32%.

Dumbovic et al. (2012) perform a rigorous statistical investigation on many areas of Forbush declines. The results of the study give empirical support for physics explanations of short-term cosmic ray modulations. The study discovered discrepancies in the association between certain solar wind disturbances and cosmic ray depression characteristics. The amplitude of the depression was shown to correlate strongly with the amplitudes of magnetic field strength and fluctuations for ICMEs, but only with the amplitude of the depression and the solar wind disturbance dimension proxy vtB for CIRs. For shock and no-shock situations, same behaviour was seen. CIR/ICME composites exhibit a unique behaviour that is a combination of ICMEs and CIRs. We discovered that the duration of the depression coincides with the duration of the solar wind disturbance in all investigated categories. Because the examination of the over-recovery revealed no direct link to either the "branching-effect" or geomagnetic influences, we suggest a scenario in which the "branching-effect" is induced by numerous variables and is only indirectly connected to the over-recovery.

Sham Singh and A. P. Mishra (2012) investigated the influence of solar and interplanetary plasma and field on geomagnetic activity. The driving forces responsible for causing space-weather disturbances have been examined. The interplanetary medium environment near Earth is characterised by disturbances emanating directly from the solar and interplanetary medium, such as solar flares, X-ray flares, coronal holes, CMEs, and the interplanetary magnetic field. Coronal mass ejections (CMEs) have a large influence on space weather and can affect the Earth in a variety of ways. Furthermore, the effect of solar phenomena and accompanying interplanetary disturbances offers a once-in-a-lifetime chance to comprehend the relationship between solar, interplanetary, and geomagnetic activity. The investigation of solar, interplanetary, and geomagnetic parameters enables the identification of disturbances and their influence on space weather interaction in the interplanetary magnetic field.

V. A. Dergachev et al. (2012) studies have shown that, in addition to the role of solar variability, past climate changes may have been connected with variations in the Earth’s magnetic field elements at various timescales. An analysis of variations in geomagnetic field elements, such as field intensity, reversals, and excursions, allowed us to establish a link between climate changes at various timescales over the last millennia. Of particular interest are sharp changes in the geomagnetic field intensity and short reversals of the magnetic poles (excursions). The beginning and termination of the examined geomagnetic excursions can be attributed to periods of climate change. In this study, we analyzed the possible link between short-term geomagnetic variability (jerks) and climate change, as well as the accelerated drift of the north magnetic pole and surface temperature variations.

Elena Saiz et al. (2013) compile the most significant data collected during the COST Action ES0803. We show that accumulating specific data, such as X-ray solar flares, Type II and/or Type IV radio emission, and solar energetic particle enhancements as inputs to an end-to-end forecasting strategy using an artificial neural network improves predicting outcomes. The geomagnetic reactions at high and low latitudes are examined independently in the issue of solar wind-magnetosphere-ionosphere interaction. At low latitudes, we give fresh insights into the temporal evolution of the ring current, as shown by Burton's equation, during the storm's main and recovery stages. At high latitudes, the PCC index looks to represent a breakthrough in modelling the connection between the upper atmosphere and the solar wind, with significant forecasting potential. We also discuss the importance of small-scale field-aligned currents in ionosphere Joule heating even under non-disturbed circumstances. Our scientific findings within the scope of COST Action ES0803 range from the short-term development of solar activity, i.e., space weather, to the long-term evolution of relevant solar/heliospheric/magnetospheric parameters, i.e., space climate.

Oh, Suyeon et al. (2013) have speculated that the solar cycle 23/24 minimum will indicate the onset of a grand minimum of solar activity, such as the Maunder Minimum. We check the trends of solar (sunspot number, solar magnetic fields, total solar irradiance, solar radio flux, and frequency of solar X-ray flare), interplanetary (interplanetary magnetic field, solar wind and galactic cosmic ray intensity), and geomagnetic (Ap index) parameters (SIG parameters) during solar cycles 21-24. Most SIG parameters during the period of the solar cycle 23/24 minimum have remarkably low values. Since the 1970s, the space environment has been monitored by ground observatories and satellites. Such prevalently low values of SIG parameters have never been seen. We suggest that these unprecedented conditions of SIG parameters originate from the weakened solar magnetic fields. Meanwhile, the deep 23/24 solar cycle minimum might be the portent of a grand minimum in which the global mean temperature of the lower atmosphere is as low as in the period of Dalton or Maunder minimum.

Ahluwalia.H.S (2014) projected the smooth sunspot number (SSN) at peak (Rmax) and the rising time (Tr) for a solar cycle using popular approaches. The geomagnetic precursor estimations provide the best forecast of Rmax for five SSN cycles (2024). An empirical method based on three cycle quasi-periodicity (TCQP) in the Ap index, in particular, has produced accurate forecasts of Rmax and Tr for two consecutive SSN cycles (23 and 24). The dynamo theories cannot explain for TCQP. If it survives until the twenty-first century, the Sun will reach a Dalton-like grand minimum. The present situation of cycle 24's ascending phase is discussed, as is the delayed reversal of the solar polar field reversal in the southern hemisphere in September 2013.

According to Liou et al. (2014), the July 23, 2012 CME was an extraordinarily quick backside event, reaching about 1AU (STEREO-A) in 20 hours as opposed to 3-6 days for ordinary CME occurrences. In general, the model findings agree well with in situ data in terms of the arrival time of the CME-driven shock and overall magnetic field strength, assuming an initial CME speed of 3100 kms^{-1}. According to an empirical model extrapolation, the rapid CME and its enormous magnetic field are capable of causing an extraordinarily massive geomagnetic storm, equivalent to the well-known Halloween storm in 2003, if the CME made a direct impact on the Earth. They looked at the impact of the adiabatic index (γ). It was discovered that for a lower value, the shock arrives somewhat later, γ and (γ) =5/3 offers the best agreement for the shock arrival time.

Prithvi Raj Singh et al. (2016) study of influence of solar activity, cosmic ray intensity and geomagnetic activity on Earth's climate during solar cycles 22, 23 and 24 has been done. The change in Earth's climate, specifically the change in the global mean temperature has been associated with the variation of some solar activity indices, cosmic ray intensity and geomagnetic activity indices in the period of 1986-2014 (Till Dec.). The important solar indices that are total solar irradiance (TSI), Sunspot Number (SSN), F10.7 index, Cosmic Ray Intensity (CRI) Kiel (NM), geomagnetic ac-tivity indices Auroral Electrojet Index (AE) and aa index, have been presented. The study of the Earth's climate in relationship with solar activity, cosmic ray intensity and geomagnetic activity has been analysed with variations and correlations. The variations of SSN with CRI are in anti- phase; SSN with F10.7, SSN with TSI, SSN with AE, SSN with aa are in same phase. The correlation of SSN with CRI is strongly negatively correlated; SSN with F10.7, SSN with TSI is strongly positively and SSN with AE, SSN with aa positively correlated to averaging solar cycles 22, 23 and 24. The Earth's climate will be affected by the solar activity, cosmic ray intensity and geomagnetic activity.

S. K. Pandey and S. C. Dubey (2017) study the influence of Solar and Interplanetary Disturbances on Space Weather. Solar activity is the dynamic energy source that drives all solar events that influence space weather. The Sun has more intense outbursts during an active solar era. Solar flares (SFs) and coronal mass ejections (CMEs) fire intense and highly charged particles at Earth, causing ionospheric and geomagnetic disruptions. Some geomagnetic disturbances fill the night sky with beautiful sheets of red and green known as auroras or northern and southern lights. All of these events are most common during the peak of each 11-year cycle of solar activity. The Maunder minimum (1645-1715) was a time when there were very few sunspots detected. The Earth's climate was colder than usual throughout this time period. This time corresponds to the linkages between the solar cycle and climate change. The particles and electromagnetic radiations emitted by solar activity outbursts have a significant impact on long-term climate fluctuations.

Catia Grimani et al. (2019) role of high-energy particles in limiting the performance of on board instruments was studied for the European Space Agency (ESA) Laser Interferometer Space Antenna (LISA) Pathfinder (LPF) and ESA/National Astronautics and Space Administration Solar Orbiter missions. Particle detectors (PD) placed on board the LPF spacecraft allowed for testing the reliability of pre-launch predictions of galactic cosmic-ray (GCR) energy spectra and for studying the modulation of proton and helium overall flux above 70 MeV n^{-1} on a day-by-day basis. GCR flux variations up to approximately 15% in less than a month were observed with LPF orbiting around the Lagrange point L1 between 2016 and 2017. As a result, small Forbush decreases cannot be considered good proxies for the transit of interplanetary coronal mass ejections and for geomagnetic storm forecasting.

Esther A. Hanson (2021) analysis showed that SSN variation was in-phase with Geomagnetic aa-index in all the solar cycles studied. Thus, Geomagnetic aa-index can be used as a proxy for studying solar magnetic activities. Performance of Regression Analysis showed that SSN regressed on SAT and Rainfall amounted to an average of 0.49 and 0.02% respectively throughout Solar Cycles 22–24. Furthermore, a regression of Geomagnetic aa-index on SAT and Rainfall yielded an average of 0.145 and 0.125% respectively. Our models showed that the variability of SAT and Rainfall in Wet Zone West Africa during Solar Cycles 22–24 are far less than 1%. Hence, the influence of SSN and Geomagnetic aa-index on SAT and Rainfall is less than 1%; and could cause 'very small' effect. These weak impacts are proofs that the variability of SAT and Rainfall were most probably not effected by SSN and Geomagnetic aa-index. Consequently, the variability of SAT and Rainfall in Wet Zone West Africa could not be attributed to SSN and Geomagnetic aa-index. We therefore, attempt to conclude that climate variability in Wet Zone West Africa is most probably not driven by solar magnetic activity, but could be attributed to anthropogenic activities.

Gopalswamy et al (2022) explosion of space weather research since the early 1990s has been partly fueled by the unprecedented, uniform, and extended observations of solar disturbances from space- and ground-based instruments. Coronal mass ejections (CMEs) from closed magnetic field regions and high-speed streams (HSS) from open-field regions on the Sun account for most of the disturbances relevant to space weather. The main consequences of CMEs and HSS are their ability to cause geomagnetic storms and accelerate particles. Particles accelerated by CME-driven shocks can pose danger to humans and their technological structures in space. This review article summarizes major milestones in understanding the connection between solar variability and space weather.

OBJECTIVE OF THE STUDY

The main aim of the study is to find out the cause of geomagnetic storm on 13 March, 1989 of solar cycle 22.

OBSERVATIONAL RESULTS AND DISCUSSION

Analysis of this section, we have taken daily average value data of solar parameter (sunspot number and solar proton flux) and geomagnetic disturbance indices (Ap, Kp and Dst) as well as daily average value data of solar parameter (solar flare class and frequency occurrence of solar flare) and cosmic ray intensity from ground based neutron monitor of Moscow having magnetic cut-off rigidity (Rc ~ 2.42 GV) and coordinate on earth is latitude 55.46N as well as longitude 37.32E. For analysing our results we have taken Loowe and Pollse Dst index and 5 level geomagnetic storm scale (G scale) and solar storm scale (S scale) from NOAA. The table given below will help with that. Figure 1 have shown the x class solar flare associated with no. of x class solar flare. The flare ejects the clouds of electrons, ions and atoms through the corona of the sun into space.

These clouds typically reach the earth one or two days. On 6 March (65th days) of year 1989, huge solar flare event (X15 class) occurred on the surface of the sun consequently, this flare built a background path between sun and earth via interplanetary medium for the other solar flare, SPEs (Solar proton events) and CMEs (Coronal mass ejections) by Soho. After the 6 March 1989, large no. of solar flare event occurred up to 13 March 1989 i.e. shown in figure 1, 2 and 3. Figure 4 has shown the sunspot number associated with the flare class.

The sunspot activity increases from the 6 March up to 9 March consequently; a big halo CME event occurred on 9 March 1989. We have study that the CMEs reach to the earth one or five days. After three days (12 March) this CMEs event arrived onto the surface of earth. We have studied that CMEs have a large number of solar plasma and magnetic field. This plasma consists of mostly electrons, protons and alpha particles with energy usually between 1.5 to 10 KeV. The solar plasma has typically velocity of 750 km/second a temperature of 8×10^5 K. Near earth surface the CMEs firstly interact to the cosmic rays which coming continuously from the interstellar space give result cosmic ray intensity decreases which are shown in figure 6. After few minutes interacting with cosmic rays this halo CMEs event arrived same days (12 March) onto the magnetosphere give a result of geomagnetic storm. For monitoring geomagnetic storm we have used three geomagnetic indices i.e. Dst, Ap and Kp.

The disturbance storm time (Dst) index is measure in the context of space weather. It gives introduction about the strength of the ring current around the earth caused by solar protons and electrons (Masters and Jeff, 2012). The ring current around earth produces a magnetic field that is directly opposite earth magnetic field. If the difference between solar electrons and protons gets higher, then earth magnetic field becomes weaker. A negative Dst value means the earth magnetic field is weakened which is shown in figure 7, this is particularly the case during solar storm. The Ap index provides a daily average level for geomagnetic activity shown in figure 8 associated with solar flare class. The Ap values is obtained by averaging the eight, 3-hour value of ap for each day.

To get these ap values you first need to convert the 3-hour Kp values to ap values. The Ap value is thus a geomagnetic activity where days high levels of geomagnetic activity have a higher daily Ap values. It means 13 March have a higher geomagnetic activity. The Kp index is global geomagnetic storm index shown in figure 9 associated with solar flare class. The Kp index ranges 0 to 9, where a value 0 means that is very little geomagnetic activity and a value of 9 means extreme geomagnetic storming. The aurora could have been seen as far south as Texas. In addition to their currents produced in the magnetosphere that follow the magnetic, called Field aligned currents and these connect to intense current in the auroral ionosphere. These auroras are the indication of Earth magnetic storm. The correlative study of this article is shown in figure 10. If we saw the positive peak of figure 4, 5, 8 and 9 having a same polarity during March 1989, resulting gave the sign of geomagnetic disturbance storm during this period. Similarly, the negative peak of figure 6 and 7 gave same result during March 1989.

The statistical results obtained here over a short period of time signify that the 13-march geomagnetic storm of solar cycle 22 is biggest event after Carrington event 1859 (Lerner and Eric, 1995). As like Carrington event this was disrupted major of human atmosphere and communication system.

TABLE 1- LOOWE AND POLLSE Dst INDEX

Geomagnetic storm	**Dst index**
Weak storm	Dst > -50nT
Moderate storm	100nT < Dst ≤ -50nT
Intense storm	-250 < Dst ≤ -100nT
Super storm	Dst ≤ -250nT

TABLE 2: LIST OF GEOMAGNETIC (G) SCALE.

Scale	G0	G1	G2	G3	G4	G5
Kp	39	50	61	72	85	96
Ap	26	47	81	131	206	402

TABLE 3 - LIST OF NOAA S – SCALES

Scale	S1	S2	S3	S4	S5
Type of storm	Minor storm	Moderate storm	Strong storm	Severe storm	Extreme storm
Intensity of Flux (particle cm^{-2} s^{-1} sr^{-1})	10^1	10^2	10^3	10^4	10^5

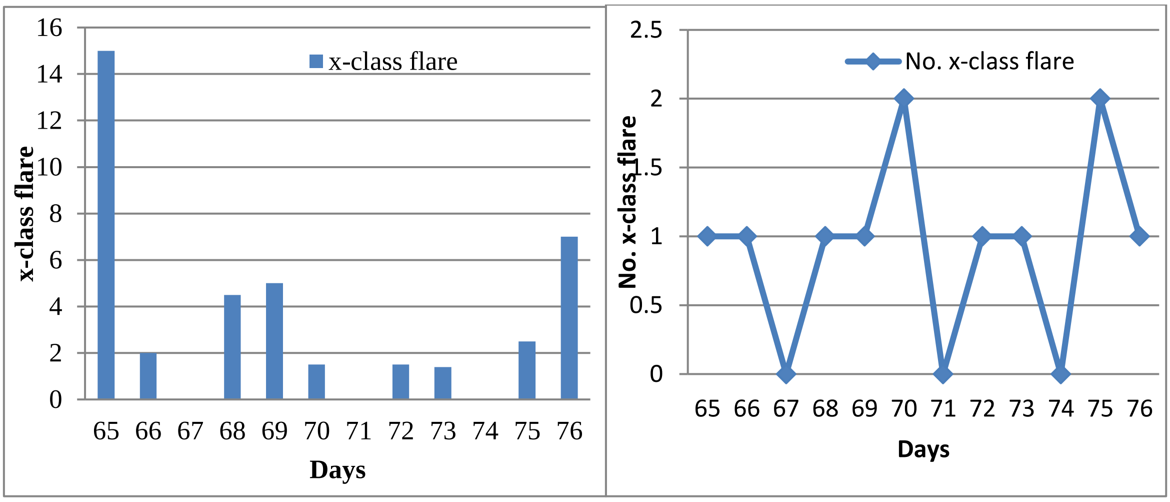

Figure 4.10: Time profile of x- class solar flare and No. of x-class solar flare during the time period from 65th to 76th day of March 1989

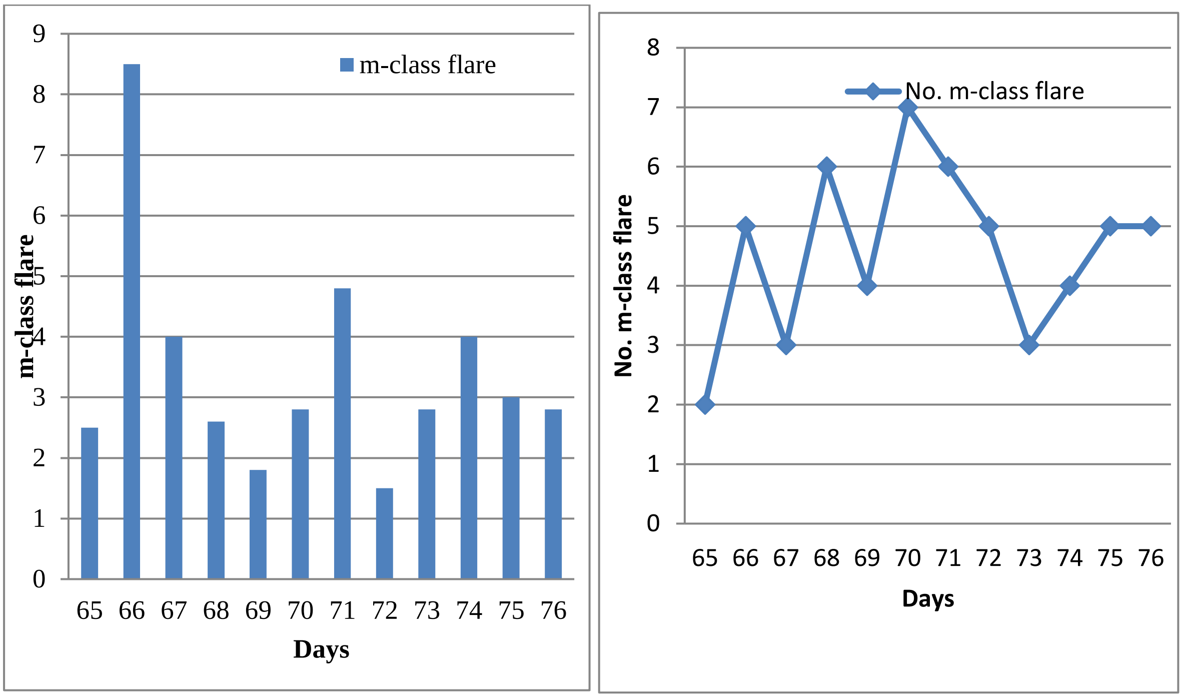

Figure 4.11: Time profile of m- class solar flare and No. of m-class solar flare during the time period from 65th to 76th day of March 1989.

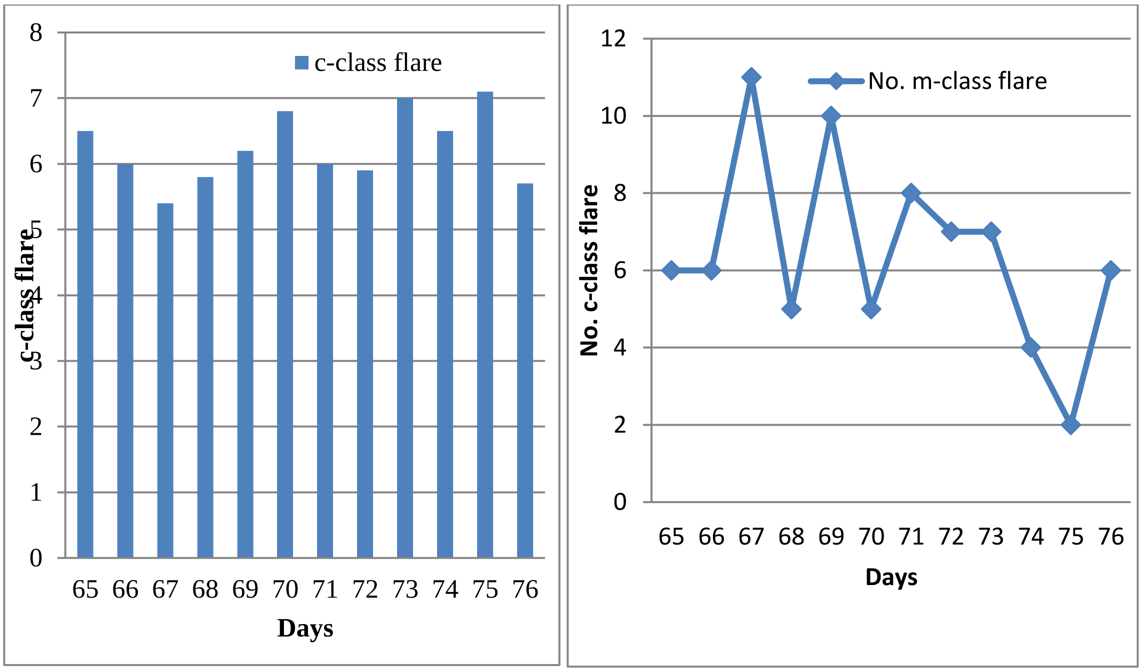

Figure 4.12: Time profile of c- class solar flare and No. of c-class solar flare during the time period from 65th to 76th day of March 1989.

Figure 4.13: Time profile of R (sunspot number) and flare class during the time period from 65th to 76th day of March 1989.

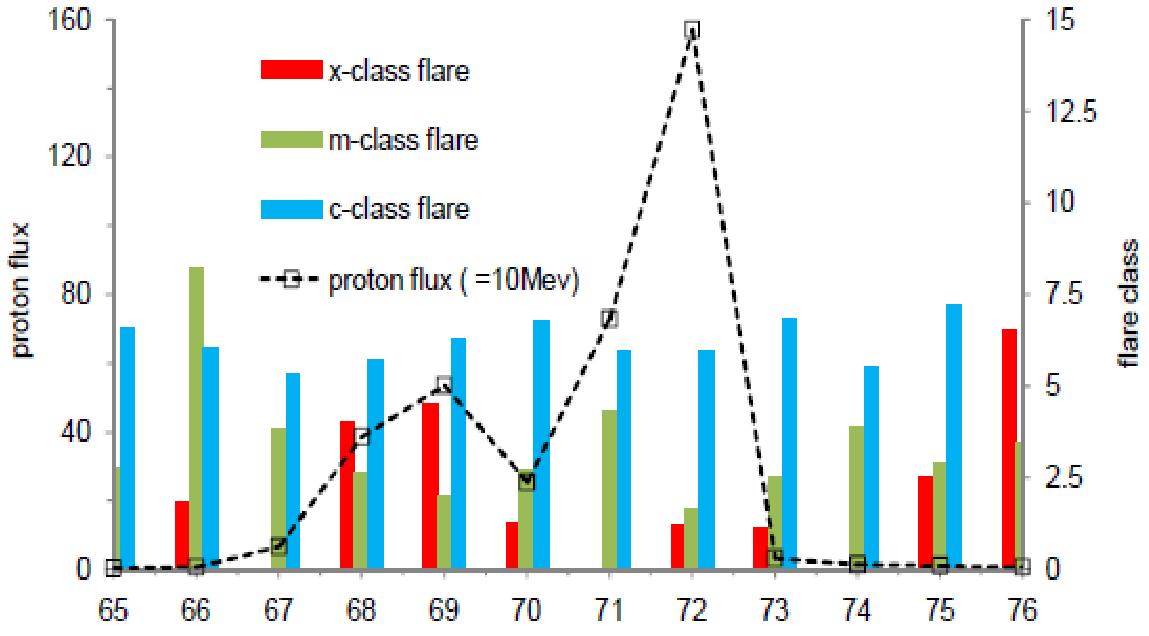

Figure 4.14: Time profile of proton flux and flare class during the time period from 65th to 76th day of March 1989.

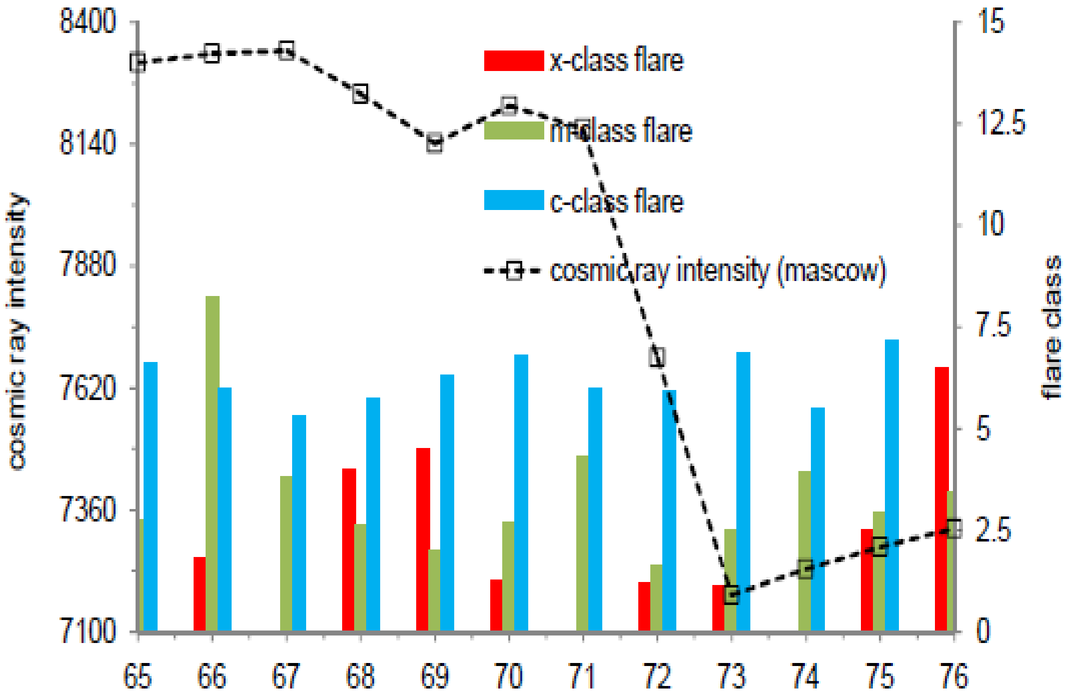

Figure 4.15: Time profile of cosmic ray intensity and flare class during the time period from 65th to 76th day of March 1989.

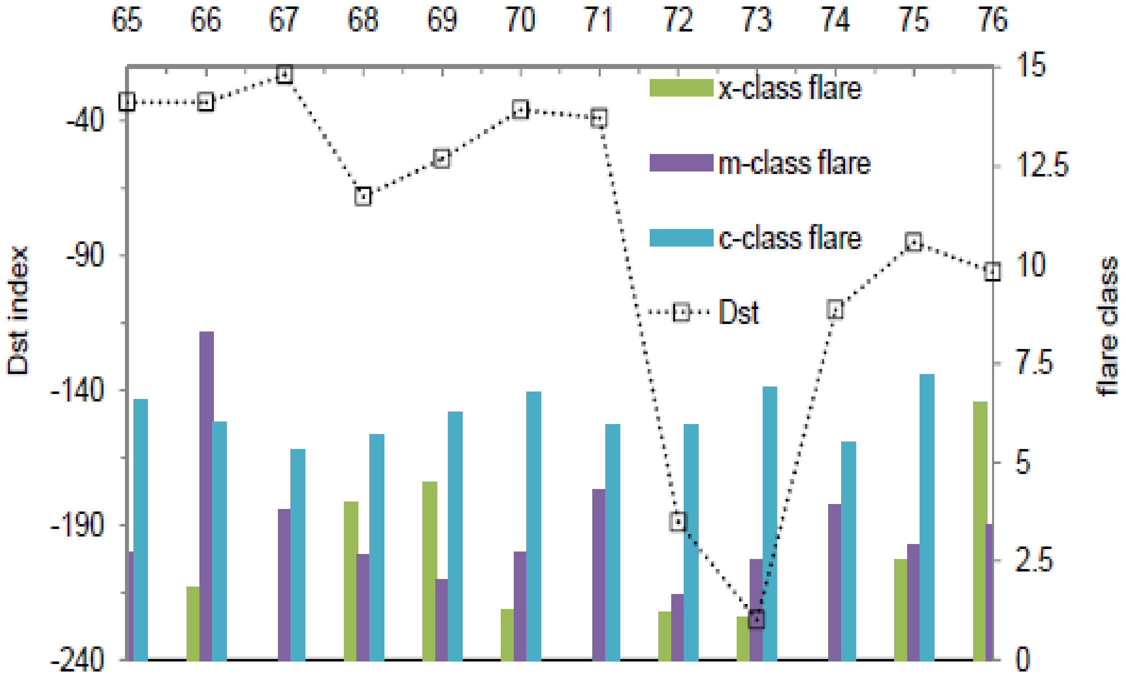

Figure 4.16: Time profile of Dst index and flare class during the time period from 65th to 76th day of March 1989.

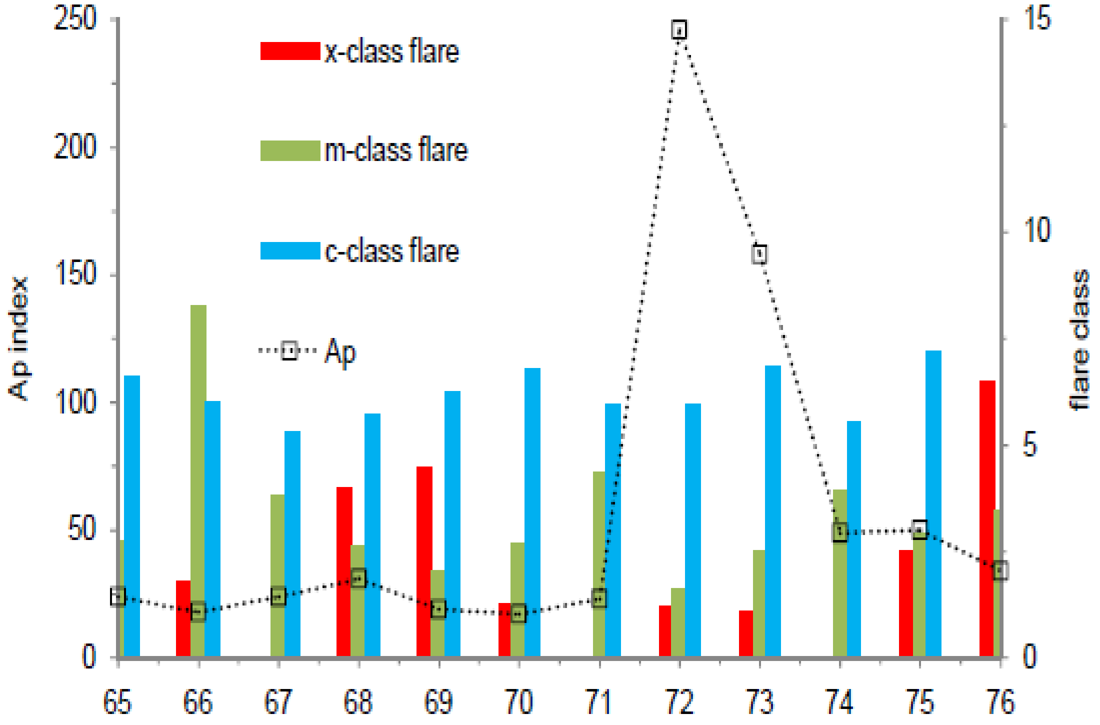

Figure 4.17: Time profile of Ap index and flare class during the time period from 65th to 76th day of March 1989.

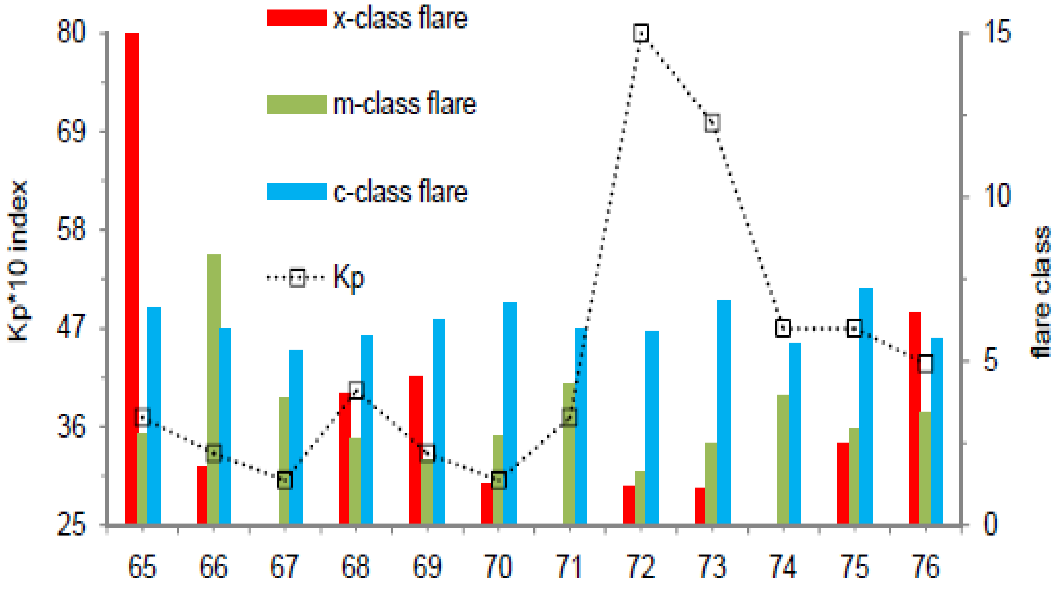

Figure 4.18: Time profile of Kp index and flare class during the time period from 65th to 76th day of March 1989

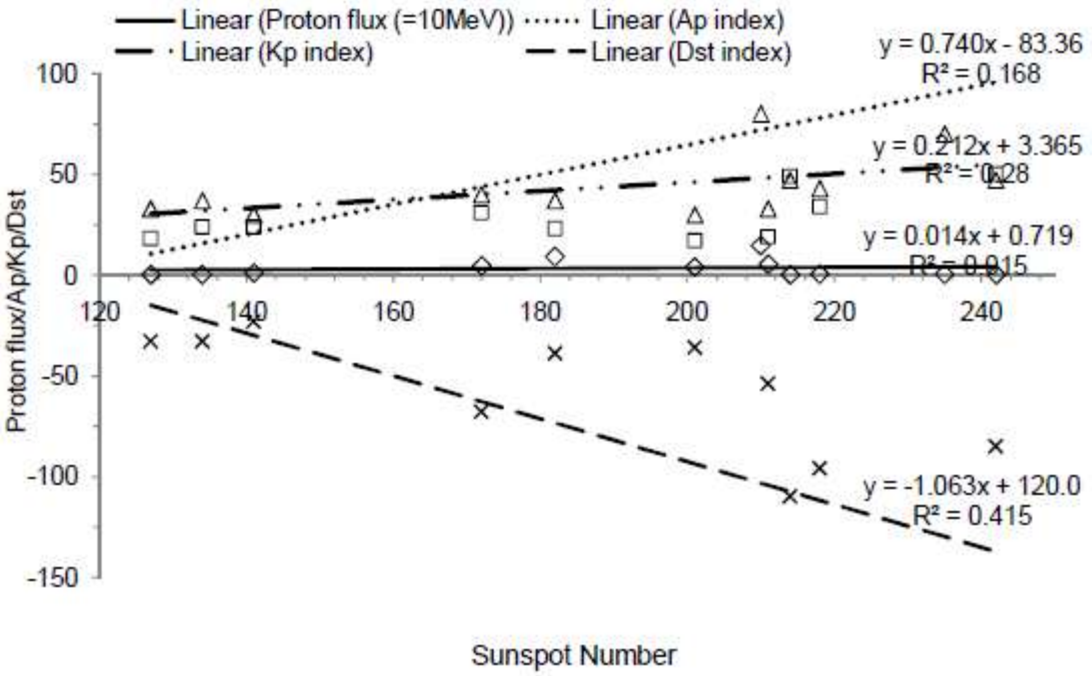

Figure 4.19: Cross plot between Sunspot number and (Proton flux, Ap, Kp and Dst Index) during the time period from 65th to 76th day of March 1989.

CONCLUSIONS

On the basis of observational results and discussion from the above figure, we have found the following conclusions:

- These clouds typically reach the earth one or two days, On 6 March (65th days) of year 1989, huge solar flare event (X15 class) occurred on the surface of the sun consequently.
- After the 6 March 1989, large no. of solar flare event occurred up to 13 March 1989
- The sunspot activity increases from the 6 March up to 9 March consequently; a big halo CME event occurred on 9 March 1989.
- The plasma consists of mostly electrons, protons and alpha particles with energy usually between 1.5 to 10 KeV.
- The solar plasma has typically velocity of 750 km/second a temperature of 8×10^5 K. Near earth surface the CMEs firstly interact to the cosmic rays which coming continuously from the interstellar space give result cosmic ray intensity decreases.
- The Ap index provides a daily average level for geomagnetic activity shown in figure 4.17 associated with solar flare class. The Ap values is obtained by averaging the eight, 3-hour value of ap for each day.
- The Kp index ranges 0 to 9, where a value 0 means that is very little geomagnetic activity and a value of 9 means extreme geomagnetic storming.

- The statistical results obtained here over a short period of time signify that the 13-march geomagnetic storm of solar cycle 22 is biggest event after Carrington event 1859.

REFERENCES

1. Carrington, R.C. and Hodgson (1859). A storm appeared on the surface of the Sun, Royal Astronomical society, 20, 13.
2. Gonzalez, W.D., Joselyn, J.A., Kamide, Y., Kroehl, H.W., Rostoker, G., Tsurutani, B.T. and Vasyliunas, V.M. (1994). What is a geomagnetic storm? Journal of Geophysical Research, 99, 5771.
3. L. I. Dorman et al. (1993) "The use of cosmic rays for continuous monitoring and prediction of some dangerous phenomena for the earth's civilization" 208, pages55–68 (1993) https://link.springer.com/article/10.1007/BF00658132.
4. Juckett et al. (1998) "Desferrioxamine enhances the effects of gamma radiation on clonogenic survival and the formation of chromosomal aberrations in endothelial cells" PMID: 9525496,1998 Apr;149(4):330-7.
5. M. Neugebauer et al. (1999) "The three-dimensional solar wind at solar activity minimum" First published: 01 February 1999 https://doi.org/10.1029/1998RG900001Citations: 34.
6. Dvornikov and Sdobnov (1996) et al. "On the quasi-ten-day periodicity of explosive processes on the Sun and their manifestations in the heliosphere and the Earth's magnetosphere" Volume 17, Issues 4–5, 1996, Pages 323-326,https://doi.org/10.1016/0273-1177(95)00594-5
7. Rajesh KUMAR Mishra (2008) "Solar Cycle Variation of Cosmic ray Intensity along with Interplanetary and Solar Wind Plasma Parameters", September 2008Latvian Journal of Physics and Technical Sciences 45(3):63-68, DOI:10.2478/v10047-008-0013-7.
8. Kalpana singh (2008) Solar and interplanetary disturbances responsible for geomagnetic storms, J. Phys.: Conf. Ser. 208 012068.
9. Dumbovic, et al. (2012). Cosmic ray modulation by different type’s solar wind disturbances, Astronomy & Astrophysics, A&A 538, A28 (2012), DOI: 10.1051/0004-6361/201117710.
10. A. P. Mishra and Sham Singh (2012) "Effect of solar and interplanetary disturbances on space-weather", January 2012Indian Journal of Scientific Research 3(2):121.
11. Dergachev, V.A., Vasiliev, S.S., Raspopov, O.M. et al. Impact of the geomagnetic field and solar radiation on climate change. Geomagn. Aeron. 52, 959–976 (2012). https://doi.org/10.1134/S0016793212080063.

12. Elena Saiz et al. (2013) "Geomagnetic response to solar and interplanetary disturbances", J. Space Weather space Clim. 3 (2013) A26, DOI: 10:1051/ swsc/2013048.
13. Oh, Suyeon et al. (2013) “Department of Astronomy and Space Science, Chungnam National University); Kim, Bogyeong (Department of Astronomy and Space Science, Chungnam National University) Received : 2013.04.11 Accepted : 2013.05.06 Published : 2013.06.15.
14. Ahluwalia.H.S (2014), An empirical approach to predicting the key parameters for a sunspot number cycle, Advances in Space Research, 53, 568–573.
15. Liou et al. (2014), Global simulation of extremely fast coronal mass ejection on 23 july 2012, Journal of Atmospheric and Solar Terrestrial Physics., 121, 32–41.
16. Prithvi Raj Singh et al. (2015) "Variability of solar cycles 22-24 in relation to cosmic ray intensity and geomagnetic parameters" International Journal of Current Research Vol. 7, Issue, 09, pp.20045-20048, September, 2015 https://www.journalcra.com/article/variability-solar-cycles-22-24-relation-cosmic-ray-intensity-and-geomagnetic-parameters.
17. S. K. Pandey and S. C. Dubey (2017) 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.
18. Catia Grimani et al. (2019) "Study of Galactic Cosmic-Ray Flux Modulation by Interplanetary Plasma Structures for the Evaluation of Space Instrument Performance and Space Weather Science Investigations" Atmosphere 2019, 10(12), 749; https://doi.org/10.3390/atmos10120749.
19. Esther A. Hanson (2021) "Impacts of sunspot number and Geomagnetic aa-index on climate of Wet Zone West Africa during solar cycles 22–24" Published online 2021 Jun 1. doi: 10.1038/s41598-021-90999-6 PMCID: PMC8169698 PMID: 34075139.
20. Gopalswamy et al (2022) "The Sun and Space Weather". Atmosphere 2022, 13, 1781. https://doi.org/10.3390/ atmos13111781 Received: 17 September 2022 Accepted: 4 October 2022 Published: 28 October 2022.
21. Masters, J. (2012). Space weather disturbance occurrence possibility, American geophysical union, 10, 32.
22. Lerner, E. J. (1995). Severe geomagnetic storm arrived on the Earth, J. Nature, 3 345.