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Effect on Major Solar Flares on AR 10720 associated with Halo Coronal Mass Ejections (CMEs)

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ABSTRACT

This research will focus on the major solar flares (X-Class) from active region AR 10720. All the data were retrieved and analysed from authority agencies which are SOHO and NOAA. From X-ray data, AR 10720 was producing 5 major solar flares namely X1.2, X2.6, X3.8, X1.3 and X7.1 from 106 of total solar flares. From data analysis, all major solar flares were associated with full halo coronal mass ejection (CME) except for solar flare X1.2. If major solar flare happened early, it will potentially to happened again in the same AR in the range 1-3 days. The speed of halo-CME was producing more than 1,000 kms^{-1}. The Dst index shows all major solar flares affected the earth magnetic field and lead to geomagnetic storms in the ranges 1-3 days after the flares events. From proton speed data shows there is no obvious pattern towards major solar flares. From of all these data, prediction of major solar flares can be made in futures research.

***Keywords*:** The Sun, Solar flares, Coronal Mass Ejections, CMEs, Geomagnetic storms

1. INTRODUCTION

The Sun is the sole source of energy in term of heat and light for the daily use on the Earth [1]. It is a G-type main-sequence star (G2V) based on its spectral class and belongs to the main sequence of the stars [2]. The Sun also having its own activities called solar activities. Solar activities are any activities that occur at the Sun especially at corona. Its

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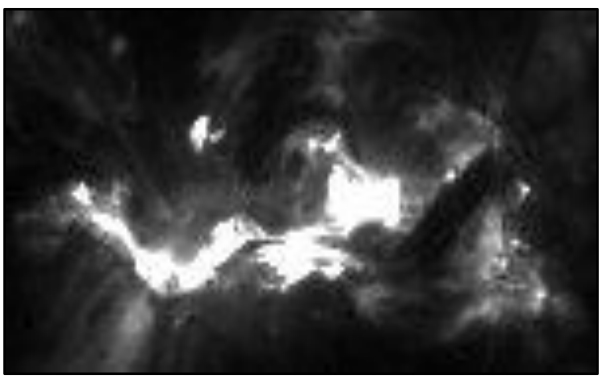
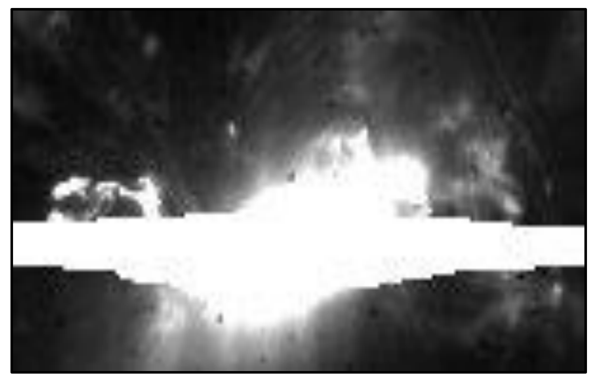
represents active regions (AR), sunspots, flares, coronal mass ejections (CMEs), solar wind and other solar eruptive events. These activities will produce massive amounts of radiation, high energy particles (electrons and sometimes protons) and high-speed solar plasma (as solar wind) into the interplanetary space. It has been revealed that the solar atmosphere has more aggressive especially in solar corona [3], [4].

Solar flares are a magnetic eruption and sudden release of intense magnetic energy at the AR (photosphere) and lasting from tens of seconds (impulsive) to a ten of minutes or hours (gradual). The AR is the region that has a strong magnetic field on the Sun photosphere and sunspots usually form at AR regions [5]. Also, it can be defined as a sudden, rapid and intense variation in brightness. Solar flares produce a burst of radiation in the electromagnetic (EM) wave from radio wave to X-rays and sometimes going to gamma rays [6]. Generally, solar flares have three main phases (figure1) which are an pre-flares phase, impulsive phase [7] and gradual phase [8]. The arcade formation and long decay event (LDE) flares can be observed in gradual phase [7], [9].



Pre-flare phase



Impulsive flare phase

Gradual flares phase

Figure 1. The example of solar flares phases for solar flare X5.7 in AR 9077 from EUV 195Å spectrum.

During pre-flares, there are appearance of sigmoidal shape just before an impulsive flare. From the images from SOHO, these sigmoidal shapes will be emergence in 12 minutes before the impulsive phase. Sometimes it appears like S, C, and J shapes [10]. The sigmoidal shape suggests that the magnetic fields are emitting their energy from magnetic twisted. This lead to the suggestion that the eruption because of magnetic twist and MHD helical kink instabilities [11], [12]. After magnetic reconnection burst (impulsive phase), the magnetic structure is continuing to reconnect in the form of arcade formation within few hours in gradual phase. During these times, it will high potential to produce CMEs. Arcade formation is emitting the radiations in soft X-rays (SXRs) and Extreme Ultra violate (EUV). The magnetic arcade loop filled by chromospheric plasma and expand into the chromosphere due to rapidly heated by thermal conduction. This expansion is known as chromospheric evaporation. The loop arcades have a gradient in temperature, with the outer loops being the hottest [13]. Later, when the temperature of arcade become cool, the arcade becomes visible at lower temperatures including EUV and H-alpha [14]–[16].

Table 1. The solar flares class and its effects toward Earth [19].

Solar Flares Class	Peak (W/m^2) between 1 and 8 Å	Effects
A	$I < 10^{-7}$	The lowest class of solar flare. These classes happen commonly during solar minimum and maximum. No harmful effects on the earth. The background flux is often in the B-range during solar maximum and in the A-range during solar minimum.
B	$10^{-7} \leq I < 10^{-6}$	
C	$10^{-6} \leq I < 10^{-5}$	Known as minor solar flares and sometimes produces the slow CME. Rarely cause a significant geomagnetic disturbance here on Earth.
M	$10^{-5} \leq I < 10^{-4}$	Medium-large solar flares may cause radio blackout and radiation storms. Strong, long duration M-class solar flares are likely to produce a CME. There is a high probability resulting geomagnetic storm.
X	$I \leq 10^{-4}$	The strongest solar flare can cause radio blackout, strong geomagnetic storming (G4 or G5) and powerful CMEs.

Solar flares are classified according to X-ray intensity in wavelength range 1 to 8 Angstroms (Å) measured by Geostationary Operational Environmental Satellites (GOES) according to the power of the X-ray flux peak classification near the Earth [17]. There are five flares class all together which are A, B, C, M, and X. Every class has 9 subs level except for X class. The dangerous flare is the X-class (major flares). It can be going up to solar flares X20.0 [18]. Every class has different consequences on Earth. Table 1 shows the solar flares class with intensity and its effect towards Earth.

Major flares (X class) are complex phenomenon occurs in a solar atmosphere with many different mechanisms. Major solar flares usually associated with halo-CMEs have strong influence interplanetary and terrestrial space by shock warn hard EM radiation, strong energetical particles (SEP), accelerated particles, geomagnetic storm etc [18], [20], [21]. Major solar flares are release solar particles at high speed and bombard the Earth magnetic field. Major solar flares associated with coronal mass ejections (CMEs) that contain 10^{12} kg of material and can move away from the Sun over 1000 kms^{-1}. At this rate, it can lead to space storm, geomagnetic storms, disturb GPS signal, increases the drag on Low Earth Orbiting (LEO) satellites, reducing their lifetime in orbit, damages on radio communication and disrupting or blowing up power system on Earth [22], [23].

Solar flares and CMEs occur due to destabilization of the magnetic structure. However, the location for both phenomena is different. In general, solar flares occur at the AR magnetic field (strong magnetic energy) while CME occurs at chromospheres magnetic field (relatively weak than AR magnetic field) [24], [25]. However, strong CME like halo-CME occur at AR which is the same location where solar flares are occurring because it requires strong magnetic energy [18], [26]. The “halo” mean that the CME is appeared fully or nearly fully surrounding the coronagraph disk. Halo-CMEs can be directly towards the Earth or toward the others way, however, ≈ 50% of halo-CMEs have a source region that towards the Earth directions [11]. The relationship between solar flares and CMEs are very complex. They do not always happen together or to drive each other [27]. However, strong solar flares like solar flares >X3.0 usually accompany with CME afterwards [28], [29].

Geomagnetic storm is the violent disturbances continuously occurred in the whole Earth’s magnetosphere for over ten hours or more [30]. The levels of the geomagnetic storm is classified according to the Disturbance storm time (Dst) index, which can be used to describe the variations of geomagnetic storms by their intensity. Dst is defined as the mean value of the variations of horizontal magnetic strength per hour observed by the stations after being normalized to the equator [30]. When Dst ≤ -30 nT, there will be a geomagnetic storm [30]. In general, geomagnetic storm can be classified into three main class (table 2).

Table 2. Dst Index and Storm level [31], [32].

DST index	Strom level
Dst < -250 nT	Super Storms (SS)
-250 nT ≤ Dst < -100 nT	Intense Storms (IS)
-100 nT ≤ Dst < -50 nT	Moderate Storms (MS)

Geomagnetic storm is particularly sensitive to intense southward interplanetary magnetic field (IMF). These IMF can transfer the magnetic energy from the high-speed solar wind which produced by solar flares or CMEs to the Earth magnetosphere. These will make disturbance to Earth's magnetosphere and leads to geomagnetic storms [31]. Statically study shows halo-CMEs have geoeffective to produce intensive geomagnetic storms [33].

The main cause of geomagnetic storms is related to IMF structures that have intense and long durations of southward magnetic fields. These southwards magnetic field orientation which interconnect with the Earth magnetic field and allow the solar wind particle to transport their energy into the inner part of Earth magnetospheres. The average speed of solar wind is ≈ 400 km s^{-1} and embedded magnetic field of ≈ 5 nT. Thus, for major geomagnetic storms, the IMF intensity should have higher than this value and higher speed of solar wind [31].

2. DATA ACQUISITION

This research has used the dataset from various authority agency. AR properties and solar flares profile are taken from the NGDC data centre under the NOAA agency. NOAA is the agency that predicting and monitoring space weather. CMEs properties were retrieved from Large Angle and Spectrometric Coronagraph (LASCO) catalogue online database. LASCO is one of the equipment onboard in the SOHO spacecraft.

The LASCO is observing the solar corona from 1.1 to 32 solar radii. It is designed to block light coming from the solar disk, in order to see the extremely faint emission from the corona region. Meanwhile, Solar wind profile and Dst index are downloaded from ECE data satellite and World Data Centre for Geomagnetism, Kyoto.

3. RESULT AND DISCUSSION

The active region (AR) 10720 was started to appear at eastern limb of the Sun on 10/01/2005 and finally disappeared at the western limb on 21/01/2005. It reaches to the maximum area on 15/01/2005 with 1,830 millionth solar hemisphere (Figure 2(a)). During its 11 days across the solar disk, AR 10270 was produced 106 solar flares (18 B class, 66 Class, 17 M class and 5 X class).

In this research, we focus more on major flares namely X1.2, X2.6, X3.8, X1.3 and X7.1 since it has very significant to the Earth. Solar X7.1 was recorded as the strongest flares in the AR. AR 10720 also have D types of magnetic configuration (Figure 2(b)). The AR that have D types of magnetic reconnection have higher tendency to produce major solar flares. The D type is very active, and the its magnetic configuration is completely intermixing with other polarity and very complex configurations [34].

The D type likely has a sharp gradient in the current sheet where the flares occur. By observation, the flash during impulsive phase occurs along the magnetic polarity inversion line (PIL) and PIL is located where D class shows it characteristics [35], [36].

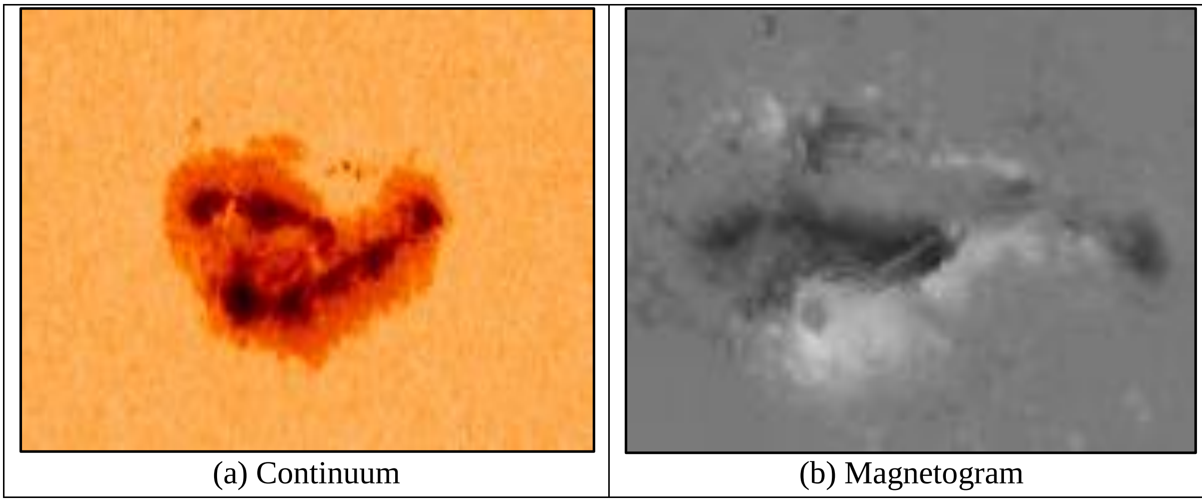


Figure 2. Active region AR 10720 in continuum and magnetogram images during Maximum area. (credit to SOHO).

3. 1. X-ray intensity and CMES

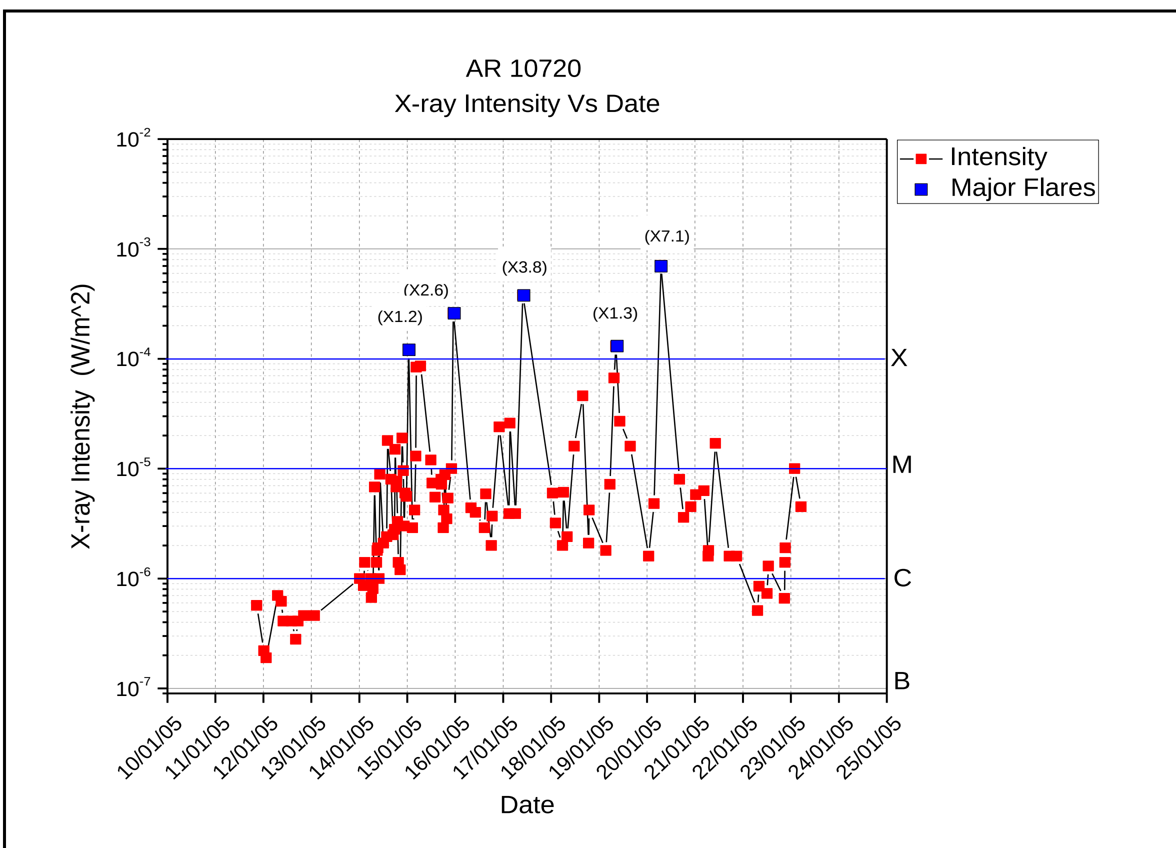


Figure 3. X-ray intensity of all solar flares in AR 10720.

The X-ray intensity data in Figure 3 shows solar flares occurrence is so rapidly on 14-15/01/2005. This figure also shows in one active region could have multiple of major solar flares. This due to the magnetic field configuration continues to reform over time or called as recurrent solar flares events [37].

Note that on 15/01/2005, there two major flares occurring on the same day but in a different time (Table 3). Besides, if the major solar flares already occur early, it will potentially happen again in the range 1-3 days. The rapid changes of magnetic configuration of the AR is possible reason of the AR to release the flares continuously. Grechnev et al. [38] study the magnetic evolutions of AR 10720 by using photospheric magnetogram images reported that the magnetic evolution in AR 10720 evolved rapidly that triggered the major solar flares occurrences. The pattern of major solar flares is very random. It is difficult to see a clear pattern on major solar flares occurrence in term of build-up energy. Table 3 shows major solar flares associated with CME with its speeds.

Table 3. Major solar flares and CME speed.

Date (solar flare Class)	Time flares (UT)	Time CME (UT)	CME Speed (kms^{-1})
15/01/2005	00:43 (X1.2)	NA	NA
15/01/2005	23:02 (X2.6)	23:06 (Halo)	2,861
17/01/2005	9:52 (X3.8)	9:54 (Halo)	2,547
19/01/2005	8:22 (X1.3)	8:29 (Halo)	2,020
20/01/2005	6:54 (X7.1)	6:54 (Halo)	3,242

All major solar flares experience halo-CME except for solar flare X1.2. The time of major solar flares and CMEs events are different in a few minutes except for solar flares X7.1, solar flare and CME time is simultaneous [28], [29]. CME speed on 20/01/2005 due to solar flare X7.1 was recorded as 882 kms^{-1} on the LASCO catalogues. The speed is quite low compared to another halo-CMEs.

This is due to the sensor at SOHO spacecraft was contaminated by SEP. Thus, the data is not reliable. However, Gopalswamy [39] made a correction and estimates a sky-plane speed of 3,242 kms^{-1} at 06:54 UT. The relation between major solar flare intensity and CME speed in Figure 4 shows there are no direct trends. It can say that CMEs speed in AR 10720 is independently from flares intensity.

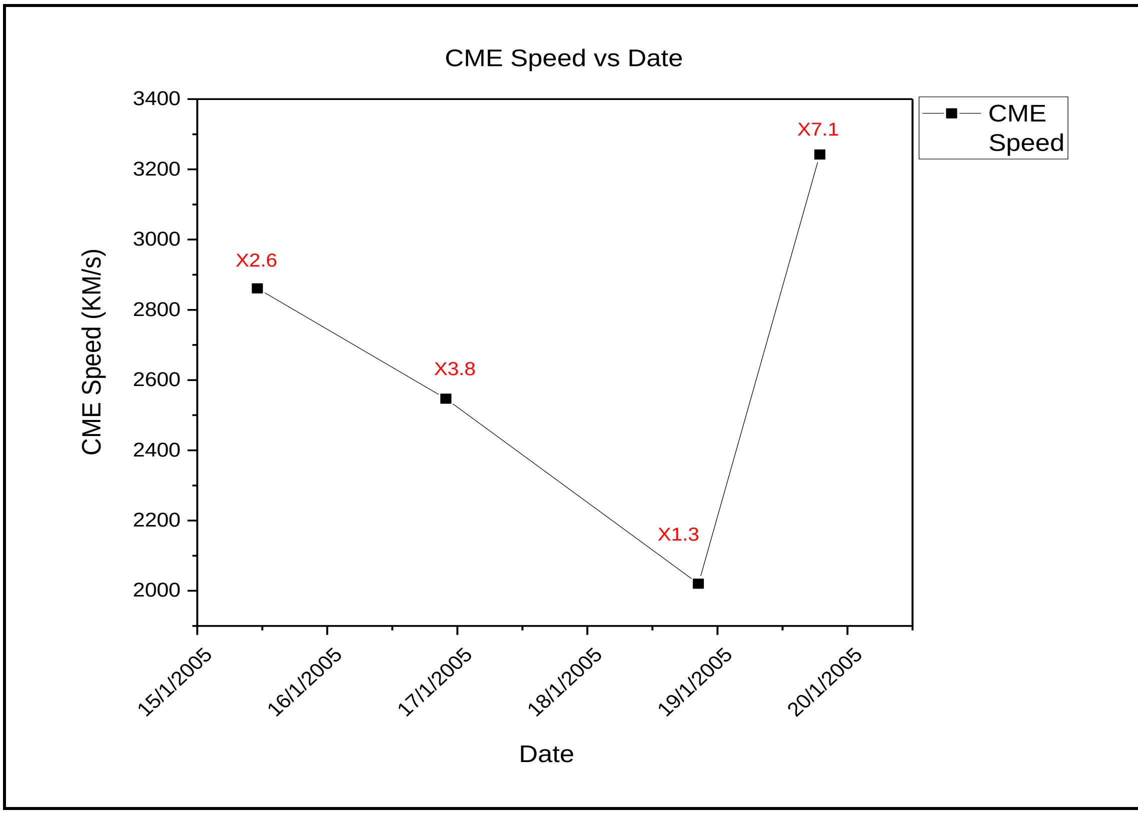


Figure 4. Correlation between CME speed and solar flares.

3. 2. Disturbance storm time (Dst) index

Dst index shows (Figure 5) there are 4 peak geomagnetic storms have occurred. There are continuous geomagnetic storms in moderate storm level was experiences in 3 days on 17-20/01/2005 and there is one intense geomagnetic storm level was happened on 18/01/2005. After further analysis, a geomagnetic storm is no happen on the same day with major solar flares.

This shows that the charger particle from solar flares and CMEs is travelling slow from the Sun relatively to the X-ray waves [40]. Therefore, the precaution steps and early warning can be announcing after major solar flares was recorded at X-ray sensors. Solar flares X1.2 and X2.6 affected on D_1, solar flares X3.8 effected on D_2, solar flares X1.3 effected on D_3 and solar flares X7.1 effected on D_4. Table 4 shows the Dst value and level.

The pattern of the proton speed (Figure 6) is cannot be seen clearly. The fastest proton speed that has been recorded is 946 kms^{-1} for solar flares X3.8. After that, the proton speed has dropped to 340 kms^{-1} despite two major solar flares occurring. On 26/01/2005, there was a rise in proton speed. However, this increasing pattern can be ignored as it has been 8 days from solar flares events. This graph shows, the proton speed is independently from solar flares event and intensity. From this graph, not all major solar flares are carrying massive amount of proton changes towards the earth.

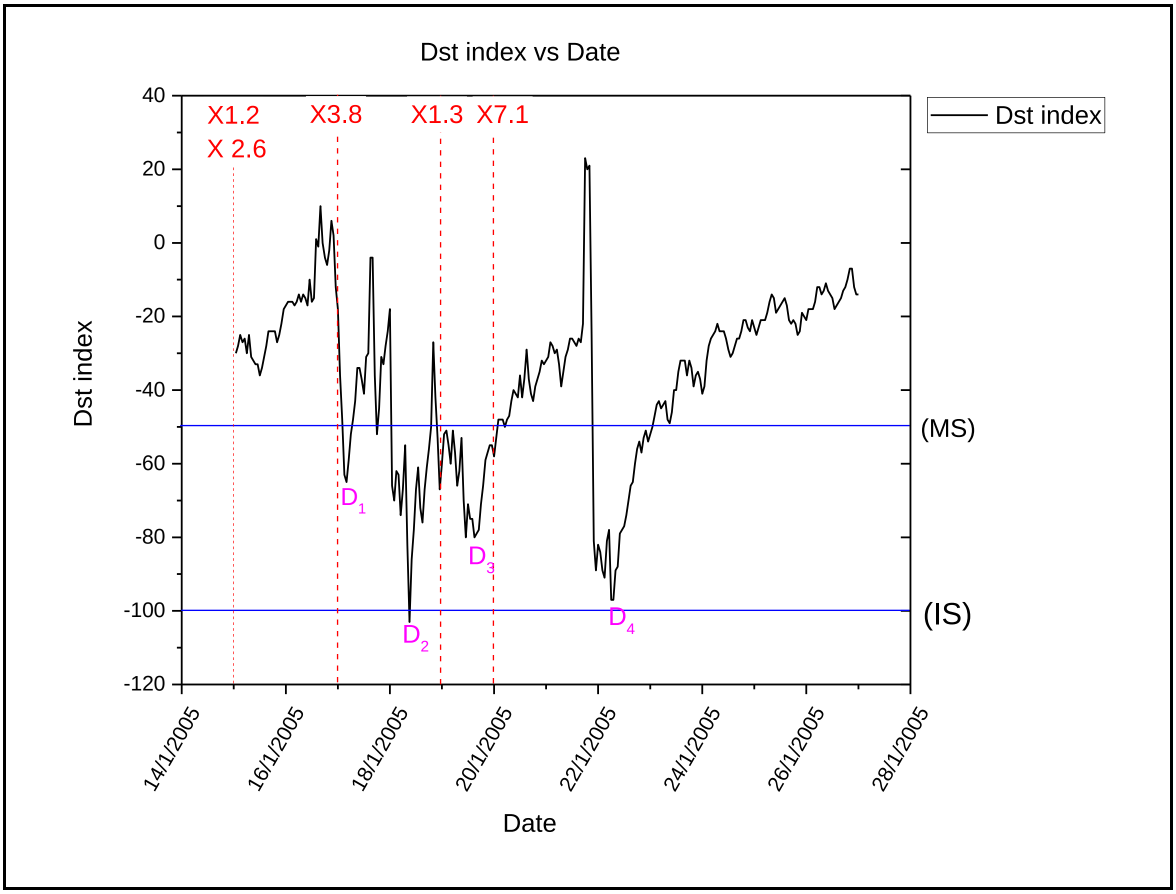


Figure 5. The Dst index from 14-27 January 2005.

Table 4. Dst value and level.

Date and Time (UT)	Dst Value	Dst level
17/1/2005 00:40	-65 (D_1)	Moderate
18/1/2005 00:90	-103 (D_2)	Intense
19/1/2005 11:00	-80 (D_3)	Moderate
22/1/2005 00:70	-97 (D_4)	Moderate

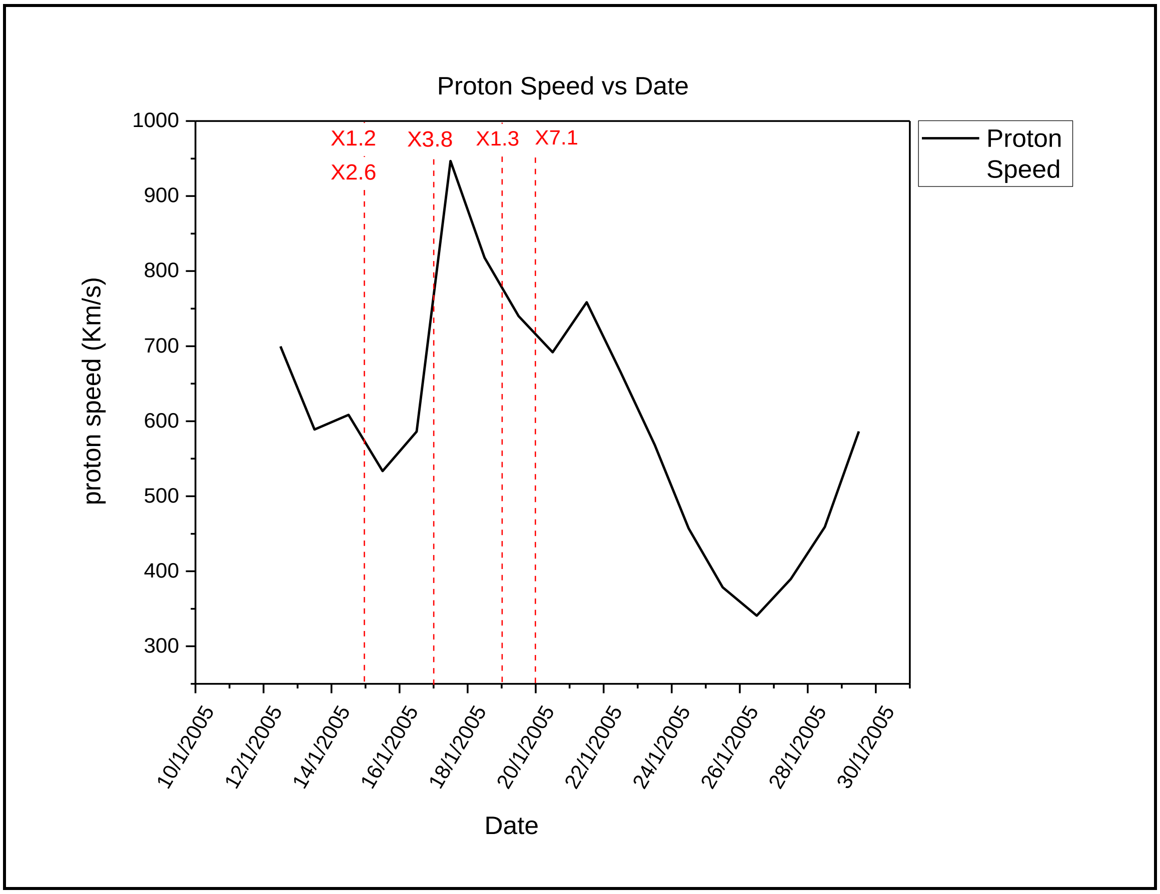


Figure 6. Proton speed during major solar flares

4. CONCLUSIONS

From this research, there 4 conclusions can be made:

1) From X-ray analysis, if the major solar flares already occur, it will potentially happen again in the range 1-3 days due to due to continuities of magnetic field reformation. The pattern of major solar flares is very random. It is difficult to see a clear pattern on major solar flares occurrence in term of build-up energy.
2) From CMEs analysis, all major solar flares were producing halo-CMEs. However, CMEs speed is independently from flares intensity. Major solar flares are procced CMEs time in few minutes.
3) From Dst index analysis, the effect of the geomagnetic storm due to major flares can be seen in the ranges 1-3 days after the major flares was detected. Thus, precaution steps can be made earlier.
4) From solar proton speed data, there is no clear pattern or relation between solar flares event and speed of proton particles. It seems that proton speed is independently from solar flares intensity.

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References

[1] J. Raulin and A. A. Pacini, Solar Radio Emissions, *Adv. Sp. Res.* vol. 35, pp. 739–754, 2005.

[2] X. Moussas, J. M. Polygiannakis, P. Preka-Papadema, and G. Exarhos, Solar Cycles: A Tutorial, *Adv. Sp. Res.*, vol. 35, no. 5, pp. 725–738, 2005.

[3] M. G. Kivelson and C. T. Russell, *Introduction to space physics*. Cambridge University Press, 1995.

[4] P. V Foukal, *Solar Astrophysics*. John Wiley & Sons, 2008.

[5] N. Gopalswamy, Coronal Mass Ejections: Initiation And Detection, *Adv. Sp. Res.* vol. 31, no. 4, pp. 869–881, 2003.

[6] A. Savcheva *et al.*, THE RELATION Between SOLAR ERUPTION TOPOLOGIES And OBSERVED FLARE FEATURES. I. FLARE RIBBONS, *Astrophys. J.* vol. 810, no. 2, 2015.

[7] M. Siarkowski, R. Falewicz, and P. Rudawy, Plasma Heating in the Very Early Phase of Solar Flares, *Astrophys. J.* vol. 705, no. 2, pp. L143–L147, 2009.

[8] H. S. Hudson, Global Properties of Solar Flares, *Space Sci. Rev.* vol. 158, no. 1, pp. 5–41, 2011.

[9] M. B. Kennedy, R. O. Milligan, M. Mathioudakis, and F. P. Keenan, Solar flare impulsive phase emission observed with SDO/EVE. *Astrophys. J.* vol. 779, no. 1, 2013.

[10] A. C. Sterling, Sigmoid CME source regions at the Sun: some recent results, *J. Atmos. Solar-Terrestrial Phys.* vol. 62, no. 16, pp. 1427–1435, 2000.

[11] Sterling *et al.*, Yohkoh Sxt and Soho EIT Observations of Sigmoid To Arcade Evolution of Structures Associated With Halo Coronal Mass Ejections, *Astrophys. J.* vol. 532, pp. 628–647, 2000.

[12] R. Liu, C. Liu, S. Wang, N. Deng, and H. Wang, Sigmoid-To-Flux-Rope Transition Leading To A Loop-Like Coronal Mass Ejection, *Astrophys. J. Lett.* vol. 725, pp. 84–90, 2010.

[13] T. G. Forbes and L. W. Acton, "Reconnection and Field Line Shrinkage in Solar Flares, *Astrophys. J.*, vol. 459, p. 330, 1996.

[14] M. J. Aschwanden and D. Alexander, Flare Plasma Cooling From 30 MK Down to 1 MK Modeled From Yohkoh, GOES, and TRACE Observations During The Bastille Day Event (14 July 2000), *Sol. Phys.* vol. 204, no. 1/2, pp. 91–120, 2001.

[15] J. W. Brosius, Chromospheric Evaporation and Warm Rain during a Solar Flare Observed in High Time Resolution with the Coronal Diagnostic Spectrometer aboard

the Solar and Heliospheric Observatory, *Astrophys. J.* vol. 586, no. 2, pp. 1417–1429, 2003.

[16] L. Fletcher *et al.*, An Observational Overview of Solar Flares, *Space Sci. Rev.* vol. 159, no. 1–4, pp. 19–106, 2011.

[17] E. Bellotti, C. Broggini, G. Di Carlo, M. Laubenstein, and R. Menegazzo, Search For Correlations Between Solar Flares and Decay Rate of Radioactive Nuclei, *Phys. Lett. B*, vol. 720, pp. 116–119, 2013.

[18] N. Gopalswamy, Corona Mass Ejections: a Summary of Recent Results, *Proc. 20th Natl. Sol. Phys. Meet.* pp. 108–130, 2010.

[19] R. Qahwaji and T. Colak, Automatic Short-Term Solar Flare Prediction Using Machine Learning And Sunspot, *Sol. Phys.* vol. 241, no. 1, pp. 195–211, 2007.

[20] B. . Somov, T. Sakaol, T. Kosugi, H. . Hudson, and S. Masuda, Modeling Large Solar Flares, *Adv. Sp. Res*. vol. 32, no. 12, pp. 2439–2450, 2003.

[21] Y. Yuan, F. Y. Shih, J. Jing, and H.-M. Wang, Automated Flare Forecasting Using A Statistical Learning Technique, *Res. Astron. Astrophys.* vol. 10, no. 8, pp. 785–796, 2010.

[22] H. Koskinen *et al.*, Space Weather Effects Catalogue, *Sp. Weather Int. J. Res. Appl.* no. 2.2, pp. 1–41, 2001.

[23] Z. Zainal *et al.*, Radio Frequency Interference In Solar Monitoring Using CALLISTO, *New Astron. Rev.* vol. 67, pp. 18–33, 2015.

[24] P. F. Chen, C. Fang, K. Shibata, and Y. H. Tang, Coronal mass ejections and emerging flux, *Adv. Sp. Res.* vol. 30, no. 3, pp. 535–543, 2002.

[25] J. Zhang, K. P. Dere, R. A. Howard, M. R. Kundu, and S. M. White, On the Temporal Relationship between Coronal Mass Ejections and Flares, *Astrophys. J.* vol. 559, no. 1, pp. 452–462, 2001.

[26] V. Ontiveros and A. Vourlidas, Quantitative Measurements Of Coronal Mass Ejection-Driven Shocks From LASCO Observations, *Astrophys. J.* vol. 693, no. 1, pp. 267–275, 2009.

[27] J. Jing, H. Song, V. Abramenko, C. Tan, and H. Wang, The Statistical Relationship between the Photospheric Magnetic Parameters and the Flare Productivity of Active Regions, *Astrophys. J.* vol. 652, no. 2, pp. 1796–1796, 2006.

[28] M. Youssef, On The Relation Between The CMEs and The Solar Flares, *NRIAG J. Astron. Geophys.* vol. 1, no. 2, pp. 172–178, 2012.

[29] A. Bemporad, A. C. Sterling, R. L. Moore, and G. Poletto, A New Variety of Coronal Mass Ejection: Streamer Puffs from Compact Ejective Flares, *Astrophys. J.* vol. 635, no. 2, pp. 189–192, 2005.

[30] Y. Zhu, W. Zong, and S. Pei, Relationship between X-class Flares and Geomagnetic Effects, *Chinese Astronomy and Astrophysics*, 2016. .

[31] W. D. Gonzalez, B. T. Tsurutani, and A. L. Clúa de Gonzalez, Interplanetary origin of geomagnetic storms, *Space Sci. Rev.* vol. 88, no. 3/4, pp. 529–562, 1999.

[32] M. Rockenbach *et al.*, Geomagnetic storm's precursors observed from 2001 to 2007 with the Global Muon Detector Network (GMDN), *Geophys. Res. Lett.* vol. 38, no. 16, pp. 5–8, 2011.

[33] H. V. Cane, I. G. Richardson, and O. C. St. Cyr, Coronal Mass Ejections, Interplanetary Ejecta and Geomagnetic Storms, *Geophys. Res. Lett.* 2000, vol. 27, no. 21, pp. 3591–3594

[34] L. M. Green, P. Démoulin, C. H. Mandrini, and L. Van Driel-Gesztelyi, How Are Emerging Flux, Flares And CMEs Related To Magnetic Polarity Imbalance In MDI Data?, *Sol. Phys.* vol. 215, no. 2, pp. 307–325, 2003.

[35] N. Deng, C. Liu, D. P. Choudhary, and H. Wang, Rapid Enhancement Of Sheared Evershed Flowalong The Neutral Line Associated With An X6.5 Flare Observed By HINODE, *Astrophys. J. Lett.* vol. 733, no. 1 PART 2, p. 66, 2011.

[36] I. Sammis, F. Tang, and H. Zirin, The Dependence of Large Flare Occurrence on the Magnetic Structure of Sunspots, *Astrophys. J.* vol. 540, no. 1, pp. 583–587, 2000.

[37] V. Polito *et al.*, Analysis and Modelling of Recurrent Solar Flares Observed With Hinode / EIS on March 9 , 2012, *Astron. Astrophys.* vol. 601, no. May, 2017.

[38] V. V. Grechnev *et al.*, An extreme solar event of 20 January 2005: Properties of the flare and the origin of energetic particles, *Sol. Phys.* vol. 252, no. 1, pp. 149–177, 2008.

[39] N. Gopalswamy, H. Xie, S. Yashiro, and I. Usoskin, Coronal Mass Ejections and Ground Level Enhancements, *29th Int. Cosm. Ray Conf. Pune*, pp. 101–104, 2005.

[40] D. F. Webb, Understanding CMEs and their source regions, *J. Atmos. Solar-Terrestrial Phys.* vol. 62, no. 16, pp. 1415–1426, 2000.