The Effectiveness of E-CALLISTO System in Predicting Geomagnetic Disturbance

Nurain Mohamad Ansor, Zety Sharizat Hamidi, Nur Nafhatun Md Shariff

Abstract: This study focuses on analyzation of solar radio burst (SRB) data obtained by e-CALLISTO system in order to predict the occurrence of geomagnetic storm. E-CALLISTO is a global network of solar spectrometer that continually generates the observed radio signals in a form of spectrographs. Previous studies have strongly proved that the source of geomagnetic disturbance turned out to be type IV SRB which can be detected by CALLISTO instrument. Therefore, we selected 4 stations located at different locations to study the effectiveness and consistency of this system in detecting type IV bursts associated to solar storm during solar maximum. The data chosen was on 10th September 2014 where type IV bursts were formed at 1727 UT until 1745 UT within a frequency range of 135MHz to 390MHz. Accompanying the bursts was a halo CME prior to the bursts' formation and an X1.6 flare was registered. From the results obtained by all stations, the pattern of the bursts depicts the same characteristic as theory says, by which, they emit a broadband continuum in a zebra pattern with varying fine structures. The formation of the bursts is due to magnetic reconnection and disruption of magnetic loops during large flares on Sept. 10th. As a consequence to type IV bursts associated to a vigorous CME, a major G2 storm was reported by NOAA a couple of days later. The presented results have shown a parallel correlation between type IV bursts detected by those 4 stations and the commencement of geomagnetic disturbance which took place 2 days afterwards.

Keywords: Coronal mass ejection, E-callisto, Geomagnetic storm, Solar radio burst type IV.

I. INTRODUCTION

Geomagnetic disturbance or normally understood as solar storm is a significant disruption that happens when high-speed solar wind from coronal holes or violent CMEs hits Earth's magnetosphere. In space weather studies, it is an indication which relates to the time-variable states in the interplanetary space that can interfere the operations of ground systems and, at the very worst, put human health or life at risk [1]. Previous study focused on analyse the relationship between solar radio burst type III with the geomagnetic storm [2]. Climate change has a close relation with the variability of the Sun's energy emitted [3]. During the disturbances, solar wind or CME's shock waves engulf the Earth's magnetosphere and compresses the field lines to the high-altitude ionosphere. The strong interaction leaves a crack on magnetosphere which allows the energetic particles brought by the solar wind to enter the magnetic fields to further contact with atmospheric particles. As the field lines come into contact with solar wind at the first place, they undergo a change in magnetic field with respect to time which can be measured by magnetometer. Space weather is substantially governed by CMEs which can affect the livings in many forms [4] [5] and several studies have underlined the roles of CMEs/ICMEs in driving space weather, specifically in geomagnetic storms [6] [7] [8]. Statistical interpretation states that most of the halos CMEs occur at average speed of ~957 km/s [9]. The energy efficiency related with solar flares may take several hours or even days to build up, but most flares take only a matter of minutes to release their dynamism [10]. Formation of aurora borealis and australis is one of the effects of geomagnetic disturbance apart from geomagnetically induced current (GIC).

The varying magnetic field converts magnetic potential energy into kinetic energy by accelerating plasmas in the solar corona and can be detected in radio burst form [11]. Solar radio bursts (SRB) are radio emissions emitted by electrons when they are accelerated to energy higher than their thermal energy. The bursts are presented by the phenomenon of temporary and intense increment in the radio spectrum or spectrograph [12]. Radio observations have been initially carried out since the discovery of radio emission waves from the Sun by J. S. Hey in 1944 [13]. It is then extended to higher level of studies as this method allows researchers in studying the energy release, plasma heating and particle acceleration [14]. SRB are recognized in five main types based on their spectral patterns and range of frequency which are type I, II, III, IV and V radio bursts. Observations of low frequency solar type III radio bursts connected with the ejection of plasma oscillations localized disturbance is due to excitation atoms in the plasma frequency incoherent energies [15]. In this study, type IV burst is selected to be analysed due to its reliability in giving hints on the upcoming disturbance other than formation of new sunspot groups. Type IV burst is the broadband quasi-continuum emission that commonly lasts for a relatively long time [16] and related to the decay phase of solar flares [17].

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There is a high probability of type IV bursts being succeeded by solar storms which can last for from hours to a few days within 20 MHz till 2 GHz [18].

Apparently, type IV bursts are observed in a zebra pattern with fine structures within a wide range of frequency. Numerous mechanisms for the zebra and fiber structures have been proposed and one broadly approved theory is DPR [19].

Type IV bursts can be generally divided into two classes – moving type IV bursts (IVm), and stationary type IV bursts (IVs). They are differed by frequency drift characteristic – type IVm potrays an obvious frequency drift, while type IVs does not [20].

Radio observations are carried out by utilising ground-based antennas which receive the radio signals and convert them to radio spectrum via spectrometer network and one of the well-known systems is e-CALLISTO. The system installation started in 2002 in Zurich, and its network has spread all around the globe ever since, benefiting researchers and individuals worldwide [21]. It is a global network of solar spectrometer [22] that consistently generates the observed radio signals in a form of spectrographs and this network is monitored under IHY/UNBSSI and ISWI instrument deployment program [23]. The overall network includes two systems – indoor and outdoor system. Indoor system consists of amplifier, receiver and PC, while antenna and low-noise preamplifier are placed outdoor. All of these components are linked and working together to produce spectrographs 24 hours throughout the year. This study is making use the results that have been obtained by e-CALLISTO to study its reliability in predicting geomagnetic disturbance.

II. DATA ACQUISITION

This study was performed by utilising data from four different stations which are a part of e-CALLISTO network. The selected stations are Bir station (Ireland), Daro-HF station (Germany), Essen station (Germany) and Roswell-NM station (USA). We chose more than one station to increase the accuracy and reliability of the obtained results on type IV bursts. The structure of antennas located at these four stations are distinct to each other as well as their frequency range. Figure 1 (a)(b)(c) show various type of antennas that were built at Bir (most left), Essen (center) and Roswell (most right). Regardless of how the antennas look like, they still operate in receiving radio signals from distant objects and transmit the signals along the conductor to an amplifier.

(a) (b) (c)

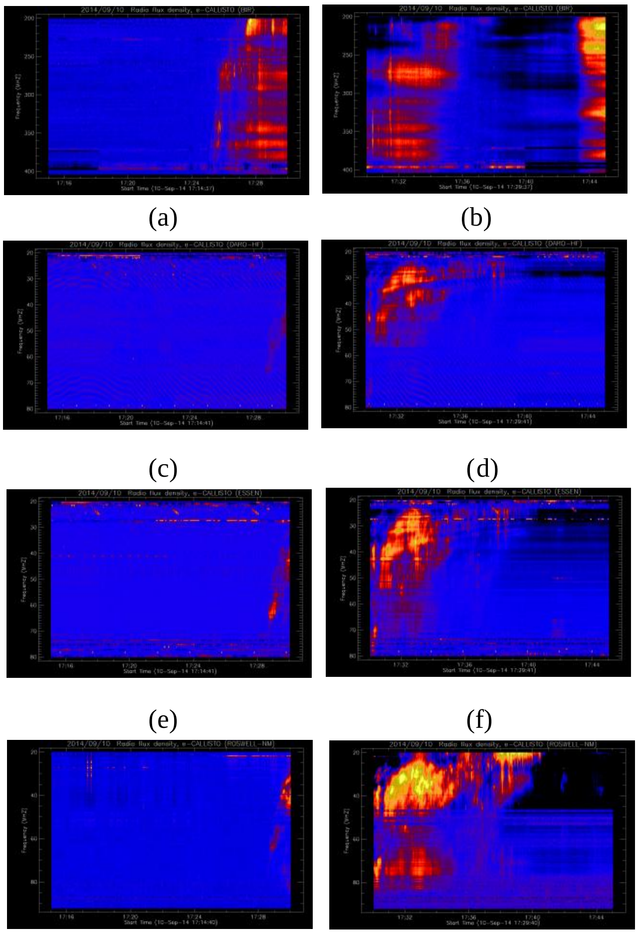
Fig. 1. (a) Dipole antenna at Bir station, (b) Dipole antenna at Essen station, (c) Dipole antenna at Roswell station.

Besides, geomagnetic parameters considered in this study are southward component of interplanetary magnetic field (IMF), Bz, AE-index and SYM-H. All of the data were obtained from OMNIWeb NASA and NOAA database. Other verified databases such as SpaceWeatherLive and Space Weather are also considered as a reference.

III. RESULT AND DISCUSSION

On 10th September 2014, a stable type IV bursts are recorded by four stations located at different continents. Bir, Daro-HF, Essen and Roswell-NM station successfully detected the similar type IV bursts in between 1727 UT until 1745 UT, fluctuating within 30MHz to 400MHz. Figure 2 (a)(b)(c)(d)(e)(f)(g)(h) show the appearance of type IV bursts during same period on the PC of all stations.

Apparently, the pattern of the bursts depicts the same characteristic as theory says, by which, they emit a broadband continuum in a zebra pattern with varying fine structures. For Daro-HF, Essen and Roswell station, the bursts began to occur at 1729 UT and settled down at 1740 UT in the range of 20-80 MHz. Meanwhile, the bursts appeared 4 minutes earlier on Bir station screen at 1725 UT and eased off at 1753 UT with the burst's frequency range of 200-400 MHz. All of the results obtained are seemed to appear in the same structure, yet, the frequency range displayed by Bir station is distinct from other stations as the antenna covers a wider range which results to a clearer and broader spectrum as seen in Figure 2 (a)(b).



(a) (b) (c) (d) (e) (f) (g) (h)

Fig. 2. (a)(b) type IV bursts recorded by Bir station, (c)(d) type IV bursts recorded by Daro-HF station, (e)(f) type IV bursts recorded by Essen station, (g)(h) type IV bursts recorded by Roswell-NM station

The formation of the bursts is due to magnetic reconnection and disruption of magnetic loops during large flares on Sept. 10th. The electrons confined in closed field lines in the post–flare arcades from the flares provoked the type IV emissions. Figure 3 shows soft X-ray flux by GOES satellite for Sep 8, 9 and 10. On Sep. 10, a powerful flare started to emerge at 1721 UT, reached its maximum intensity of X1.6 class at 1746 UT, and eased off an hour later.

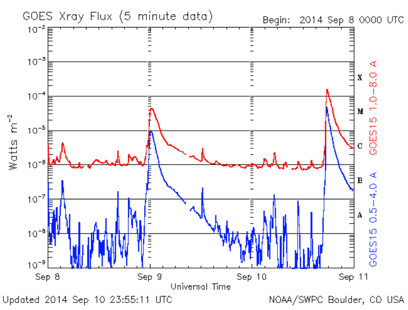


Fig. 3. GOES satellite X-ray flux for Sep. 8th, 9th and 10th.

Over the period of this flare, type IV bursts were formed as a result of magnetic reconnection process during the launch of flare. At the beginning of the flare, type IV bursts appeared in low intensity at 1727 UT as a sign of the commencement of a large flare. As the flare getting furious, type IV bursts increase in its intensity and give off a broader and continuum emissions.

On the other side, the expected geomagnetic disturbance which was hinted by type IV bursts finally arrived the Earth on Sep. 12th. Both X1.6 class flare and full halo Earth-facing CME have enhanced the shock waves hitting the Earth's magnetic fields. High energy radiation from the eruptions have ionized the upper layer of Earth's atmosphere and due to that, high frequency radio communications were crashed for more than an hour. As Earth encountered a strong shock, a G3 storm was triggered and it was one of the most intense of the year. Figure 4 displays the fluctuations of geomagnetic data on Sep. 12th during the storm event. The presented parameters are southward IMF, Bz, solar wind speed, AE-index and SYM-H. For the Bz and solar wind speed data, the ACE/WIND spacecrafts were shut down at the beginning of the day for almost four hours to protect the instruments on board as fast-drift solar wind passed by and they were back on operation at 0354 UT.

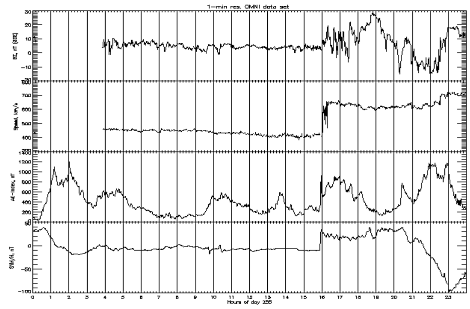


Fig. 4. Fluctuations of geomagnetic data during G3 storm on Sep. 12th

Based on the observation, the disturbance initiated at midnight until early morning with Kp-index of 5. Later on, the storm became more severe as its intensity arose to Kp 6 and further to Kp 7 at 1300 UT and midnight. During the start of the disturbance, atmospheric particles at upper layer were ionized and increased the electrojet around the E region fluctuated actively as a sign of ionosphere disturbance at 1600 UT until the end of the day as most of the values marked at high positive values. Synchronously, SYM-H values plunged to higher negative values at the same period with the maximum phases of AE-index. This signals the occurrence of the storm as SYM-H dropped to -19 nT at 0210 UT and continue to plummet to -97 nT at 2303 UT, together with the increment of electrojet.

As a result of the storm, bright auroras circling the Arctic Circle and sparkled over several US states including the sky of Maine. Other than radio communications interference, no severe damages reported on ground-based systems during the storm.

IV. CONCLUSION

In conclusion, production of type IV bursts on 10th September 2014 were able to predict geomagnetic disturbance which occurred two days later.

Four stations successfully recorded the bursts which are Bir, Daro, Essen and Roswell-NM station and they obtained the same pattern of emission spectrum at the same time. The disturbance was caused by X1.6 class flare and a full halo CME which erupted on Sep. 10th and the fast-drift solar wind from the eruptions arrived the Earth in two days. Due to the disturbance, HF radio communications were disrupted as Earth's ionosphere was ionized apart from the formation of aurora borealis over certain states of US.

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REFERENCES

1. H. Koskinen, E. Tanskanen, R. Pirjola, A. Pulkkinen, C. Dyer, D. Rodgers, P. Cannon, J. C. Mandeville and D. Boscher, Spaceweather effects catalogue. ESWS-FMI-RP- 0001 , no. 2, 2001.
2. N. A. M. Norsham and Z. S. Hamidi, "The Relationship between Solar Radio Burst Type III and Geomagnetic Storm on the Earth that Occurred on 4th October 2017.," Journal of Physics: Conference Series Vol. 1152, p. 012019, 2019.
3. N. Mohamad Ansor, Z. S. Hamidi and N. N. M. Shariff, "The Impact on Climate Change Due to the Effect of Global Electromagnetic Waves of Solar Flare and Coronal Mass Ejections (CMEs) Phenomena.," Journal of Physics: Conference Series Vol. 12, 2019.
4. N. Gopalswamy, "Coronal mass ejections of solar cycle 23," J. Astrophys. Astron. 27, p. 243, 2006.
5. M. Dumbović, A. Devos, B. Vršnak, D. Sudar, L. Rodriguez, D. Ruždjak, K. Leer, S. Vennerstrøm and A. Veronig, "Geoeffectiveness of coronalmass ejections in the SOHO Era," Sol. Phys. 290 (2), p. 579, 2015.
6. J. T. Gosling, D. J. McComas, J. L. Phillips and S. J. Bame, "Geomagnetic activity associated with earth passage of interplanetary shock disturbances and coronal mass ejections," J. Geophys. Res. 96, p. 7831, 1991.
7. M. Mierla, D. Besliu-Ionescu, O. Chiricuta, C. Oprea and G. Maris, "Studies of coronal mass ejections that have produced major geomagnetic storms," Sun Geosph. 7 (1), p. 13, 2012.
8. C. -C. Wu and R. P. Lepping, "Relationships among geomagnetic storms, interplanetary shocks, magnetic clouds, and sunspot number during 1995–2012," Sol. Phys. 291, p. 265., 2016.
9. N. N. M. Shariff, Z. S. Hamidi and N. H. Zainol, "Analysis of slow partial Halo CME events with velocity of 100-200 km/s: an observation through CALLISTO system.," in IEEE, Seoul, 2017.
10. Z. S. Hamidi, M. F. M. Noh, W. N. Toni and N. N. M. Shariff, "An Analysis of Active Region as a Trigger of Solar Flares.," Journal of Physics: Conference Series Vol. 1298, 2019.
11. Z. S. Hamidi, N. N. M. Shariff, Z. A. Ibrahim, C. Monstein, W. W. Zulkifli, M. B. Ibrahim and N. A. Amran, "Magnetic Reconnection of Solar Flare Detected by Solar Radio Burst Type III.," Journal of Physics: Conference Series Vol. 539, 2014.
12. H. Liu, Y. Chen, K. Cho, S. Feng, V. Vasanth, A. Koval, G. Du, Z. Wu and C. Li, "A Solar Stationary Type IV Radio Burst and Its Radiation Mechanism," Solar Phys 293:58, 2018.
13. J. S. Hey, S. J. Parsons and J. W. Phillips, Monthly Notices of the Royal Astronomical Society 108, pp. 354-371, 1948.
14. Z. S. Hamidi, N. N. M. Shariff, C. Monstein and Z. A. Ibrahim, "Space Weather: The Significance of e-CALLISTO (Malaysia) As One of Contributor of Solar Radio Burst Due To Solar Activity," International Letters of Chemistry, Physics and Astronomy 7, pp. 37-44, 2014.
15. Z. S. Hamidi, N. M. Anim, N. N. M. Shariff, Z. Z. Abidin, Z. A. Ibrahim and C. Monstein, "Dynamical structure of solar radio burst type III as evidence of energy of solar flares," AIP Conference Proceedings Vol. 1528, 2013.
16. M. Pick, "Sur differents aspects du rayonnement des sursauts de type IV In: Evans, J.W. (ed.) The Solar Corona," IAU Symposium 16, p. 247, 1963.
17. S. M. White, "Solar Radio Bursts and Space Weather," pp. 1-18.
18. Z. S. Hamidi and N. N. M. Shariff, "Detailed Investigation of a Moving Solar Burst Type IV Radio Emission in on Broadband Frequency," International Letters of Chemistry, Physics and Astronomy Vol. 26, pp. 30-36, 2014.
19. V. V. Zheleznyakov, "Radio Emission of the Sun and Planets," 1970.
20. M. Pick, "Observations of radio continua and terminology," Solar Phys. 104, p. 19, 1986.
21. N. H. Zainol, S. N. U. Sabri, Z. S. Hamidi, M. O. Ali, N. N. M. Shariff, N. Husien and M. S. Faid, "Effective data collection and analysis of solar radio burst type II event using automated CALLISTO network system," in IEEE, Jeju, 2016.
22. Z. S. Hamidi, N. N. M. Shariff, Z. Z. Abidin, Z. Ibrahim and C. Monstein, "ECallisto Collaboration: Some Progress Solar Burst Studies Associated with Solar Flare Research Status in Malaysia," Malaysian Journal of Science and Technology Studies 9, pp. 15-22, 2013.
23. A. O. Benz, M. Guedel, H. Isliker, S. Miszkowicz and W. Stehling, "A broadband spectrometer for decimetric and microwave radio bursts first results," Sol. Phys. 133, pp. 385-393, 1991.

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