Statistical Analysis of Solar Radio Burst Type III and Type IV with Relation to Solar Activities

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Abstract. Solar activities are natural phenomena that occur at the solar surface by ejecting energy into interplanetary space and consequently hitting Earth’s atmosphere where the commencement of geomagnetic storms. Generally, solar radio bursts originated at the same level as the solar flares, Coronal Mass Ejections (CMEs) and shock at solar atmosphere which the Sun project the radio energy into the interstellar medium. This is a novel study to investigate the correlation between solar burst type IV and type III based on their properties. The analysis is based on the statistical data of type IV and type III solar bursts from 2006 – 2011. The statistics of solar burst type IV associated with type III were obtained through e-Callisto (Compact Astronomical Low-frequency Low-cost Instrument for Spectroscopy Transportable Observatory) Spectrometer in the years 2006 until 2011. The aim of this study is to find out whether type III bursts preserved energy to solar bursts type IV thus led to the formation of geomagnetic storm. Statistical data from this study showed that most of the burst type IV were preceded and followed by type III burst. The total number of type IV events studied was 37, with 20 preceded by type III and the remainder with other types. Predominantly, solar bursts events are accompanied with great solar flares (class X and M) producing major storms. Although the study did not show much correlation between bursts type IV and type III in producing these storms, there are several possible explanations for this result. It may be the case that solar events such as solar flare, CMEs and active region ejected from the solar disc is not heading towards Earth and the energy has eventually dispersed into the interplanetary medium.

Introduction

Solar radio burst type III solar radio burst generated from the fast electron particle ejected from the Sun. One of the characteristic type III burst is the rapid drift of frequency from high to low that attribute the decreasing of electron plasma frequency. Besides, type III burst is usually long lasting, intense bursts seen in the low-frequency observations made from the space. It caused by streams of electron travelling along open field lines from flaring regions near the Sun into the interplanetary medium [1]. Type III bursts have consistently the fastest drift rates of bursts at metric wavelengths and was created by an electron beam through plasma emission. The radio emission tracks the electron beam as it travels through the decreasing plasma density of the solar corona and solar wind [2]. Meanwhile, the type III solar burst is a common signature of near-relativistic electrons streaming through the background plasma of the solar corona and interplanetary space, offering a means to remotely trace these electrons
This burst shows the coalescence of electron plasma waves from a non-thermal distribution with electron plasma waves from the distribution of thermal charge fluctuations [14, 15]. It is estimated that the total number of electrons \( \gtrapprox 22 \) keV required to produce a type III burst is \( \lesssim 10^{34} \) [16, 17]. This burst can occur singularly, in groups, or in storms. This fast drift burst is the most common of the meter wavelength bursts [18]. This main purposed of this study was intending to see the relationship of solar radio burst type IV in the presence of type III burst that associated with solar activity. Thus, led to the occurrence of a geomagnetic storm that affected the Earth magnetosphere. However, this study not focused on solar cycle whether it happens at the solar minimum or solar maximum.

These are from electron beams escaping along open magnetic field lines. Type III bursts typically start in the corona at frequencies of order 100 MHz, and then drift downwards in frequency as the driving electrons move out into the increasingly dilute plasma of the solar wind. Interplanetary type III bursts almost never show fundamental-harmonic structure. It is well accepted that type III bursts are associated with electron beams, which develop as faster electrons outrun slower electrons to form a localized hump in the electron distribution at velocities parallel to the magnetic field which are much larger than the electron thermal speed in the solar wind. Type IV are broadband quasi-continuum features associated with the decay phase of solar flares. Type IV emission has a duration of a few minutes to a few hours, covers a broad range of frequencies, varies smoothly in intensity. It generally believed to be synchrotron radiation from relativistic electrons spiralling in magnetic fields and results from trapped electron populations. There are several subclasses of type IV bursts, the type most tightly coupled to flares is called type IV continuum. The centimeter-wavelength bursts, particularly the intense ones, are closely associated with solar flares. Solar burst type IV always related to the development of sunspot groups. It has been well established that type IV bursts have a high probability of being followed by geomagnetic disturbance.

During solar flares, the X-ray flux received at the Earth increases dramatically, often within a few minutes, and then decays again in times ranging from a few tens of minutes to several hours [3]. The X-rays radiation from solar flares ionize the neutral atmosphere at D region heights greatly increasing the electron densities there and thus markedly lowering the effective VLF reflection height [4]. The energy of solar flare dependence of the decrease may go inversely with particle rigidity, or it may be flatter, depending on the details of the magnetic configuration in and around the blast wave [5, 6]. Detailed analysis on the temperature of the underlying loops increased toward higher altitudes, while the temperature of the coronal source increased toward lower altitudes [7]. The previous results of the analysis indicate that (1) most of the flare plasma was at temperatures between 3 and 10 million degrees; (2) the peak temperature decreased with time from about 8 x 10^6 K to 5 x 10^6 K over a period of 3.5 hours; (3) the differential emission measure steadily decreased with time at nearly all temperatures; (4) both radiation and conduction were important cooling mechanisms for the plasma at T>10^5 K; and (5) a substantial amount of energy, of the order of 3 x 10^{31} ergs [8]. A time-intensity profiles for solar proton events are analyzed with respect to the acceleration of energetic particles from the ambient solar wind by an interplanetary shock [9]. The uncertainty in the determination of the level of the primary electron bremsstrahlung as well as the lack of measurements on the \( \gamma \)-ray emission above 100 MeV combine to allow rather a wide range of energy distribution parameters [10]. Some of these variations were irreversible, occurred in the vicinity of magnetic neutral lines, and likely were related to magnetic energy release in the flare [11]. It is shown that Sweet's mechanism is much more effective in a highly compressible medium if the merging magnetic fields are exactly antiparallel [12].
Methodology

A statistical study of solar radio burst type III and type IV were performed using the data from Compound Astronomical Low cost Low frequency Instrument for Spectroscopy and Transportable Observatory (CALLISTO) from 2006 until 2011. Year 2006 until 2011 was chosen to examine the properties of solar radio burst type III and type IV because of the availability of archived complete list of solar radio burst data provided by e-CALLISTO website.

We use the Compound Astronomical Low cost, Low frequency Instrument for Spectroscopy and Transportable Observatory (CALLISTO) as a main system of solar radio bursts and RFI-monitoring for astronomical science and education [19-21]. The e-CALLISTO is the worldwide network connected via internet [22, 23]. This system can cover 24 hour data of solar burst, which operates identical spectrograph in different locations around the world. It is more than 133 instruments in more than 67 locations with users from more than 132 countries [24, 25]. However, it solar burst can be detected only after they have travelled far enough from the Sun [15, 26]. This system has an individual channel has 300 kHz bandwidth and can be tuned by the controlling software in steps of 62.5 kHz [27].

Results and Discussion

It is widely accepted that magnetic reconnection plays an important role in releasing the energy stored in sheared magnetic fields on the surface. In a magnetic reconnection process, oppositely directed field lines come closer and join, resulting in the release of magnetic energy in the form of thermal energy and particle acceleration (eruption of a plasma blob, associated M-class flare, and large-scale EUV wave observed by SDO. Magnetism in the Sun plays a key role in the dynamics of its surface. It is in part responsible for eruptions called coronal mass ejections that release high amounts of energy into space. Magnetism is phenomenon that arises out of the movement of electric charge, a fundamental property of matter. It creates a magnetic force, a “push” or “pull”, on objects with moving electric charge. The electrons within the magnets are thought to spin in the same direction, resulting in a magnetic field. As a result of this self-created field, each magnet has a polarity, or two poles, north and south. When a pole of a magnet is brought to the same pole of the other, the magnets repel. When the poles are different, magnets attract. As a pair magnet can show, the movement of electric charge is the driving force of magnetism. The Sun has a very weak overall magnetic field (average dipole field). However, the solar surface has very strong and tremendously complicated magnetic fields.

As it shown in the Table 1, the occurrence of type III burst more frequent compared to the type IV burst, it was recorded with 320 and 37 events respectively. The events increasingly by year as the sites of CALLISTO also increasing. The data of solar burst increased drastically in 2011 due to an additional site to detect and monitor the Sun with a longer period of observation. This is because of the increment of the CALLISTO spectrometer all over the world, thus can monitor the Sun with 24 hours per days.

| Year | Solar Radio Burst Type IV | Solar Radio Burst Type III |
|------|---------------------------|----------------------------|
| 2006 | 1                         | 15                         |
| 2007 | 0                         | 19                         |
In 2006, only a few sets of CALLISTO were installed and not cover the 24 hours Sun monitoring. In the beginning of the installation of CALLISTO spectrometer, its only have 12 sites only. Other than that, both burst rising from 2010 to 2011 because of solar activities that increase during that time which is from minimum solar cycle to maximum solar cycle.

Table 2 present the distribution of solar radio burst type IV events associated with others solar radio burst for 2006-2011. From 37 events of type IV, 20 events were preceded by type III burst and 22 events was followed by type III and the rest with other types and no burst detected. Type IV burst was preceded by 20 bursts of type III, 5 by DCIM, 2 from type II burst, 5 from type I burst and the rest of 5 with no burst detected at all. Other than that, type IV burst with 18 events was preceded and followed by both type III burst.

| Year | Type IV  | Type III Preceded | Type III Followed | Both Preceded and Followed |
|------|---------|-------------------|-------------------|---------------------------|
| 2008 | 3       | 20                | 22                | 18                        |
| 2009 | 1       | 5                 | 12                | 7                         |
| 2010 | 8       | 12                | 12                | 7                         |
| 2011 | 24      | 5                 | 3                 | -                         |
| Total| 37      | 20                | 22                | 18                        |

Table 1: Distribution of solar radio burst type IV events associated with others solar radio burst for 2006-2011.

From this table it appears that the occurrence of solar radio burst type IV mostly associated with type III solar radio burst. As this study focused only on solar radio burst type III associated with type IV, the preceded of solar radio burst type III only included based on the durations not exceeding than 24 hours before type IV occurred. Type III emission that commenced after type IV was not focused in this study. However, there were 22 events listed in the e-Calisto archived in which type III followed type IV bursts.

As a comparison, the classification is by the presence or absence of an associated type III solar radio burst. In order to examine their possible relation, the set of 37 events was divided into two groups by two classifications, one depends on the presence of type III burst that preceded type IV burst and the other on type IV burst only. Figure 2 shows plot of KP index, an index of geomagnetic variability, for several days after each of the 37 type IV events at 3-hourly intervals.
Similar trends are clear among both type IV burst in the presence of type III burst and type IV burst only. With 20 events of solar radio burst type IV preceded by type III solar radio burst, there are 5 events associated with great geomagnetic storms from 6 to 8 Kp index. 2 events with geomagnetic disturbance and the rest of 13 events are geomagnetic calm from 1 to 3. While, for type IV burst only without associated with type III burst, 5 events associated with geomagnetic storm from 5 to 8 Kp index, with three of its at 5 Kp index. 4 events of geomagnetic disturbances and 8 events of geomagnetic calm.

As can be seen, with the presence of the type III burst before type IV burst event, the association of geomagnetic storm was great compared to type IV burst only. Even though type IV burst only also have geomagnetic storm, but it occurred at the index of 5 and only two events at 7 and 8 indexes, compared to type IV that have been preceded by type III burst where it associated with 6 to 8 Kp index.

This association between type III and type IV solar radio burst can be explained by the fact that both of this solar radio burst are generated by fast electrons. The disturbance which gives rise to type III bursts have high velocities and may be either streams of electrons or fast, transverse shock. While, the electrons which give rise to type IV are principally have a similar velocity range.

Although not showing an outstanding difference in the presence and absence of type III solar radio burst as shown in Figure 2, this might be due to some other factors. Among the factors that affect the geomagnetic storm are solar flare and solar wind. Table 6.3 compares the various categories of all type IV events in the presence of type III events and type IV events only with respect to association with powerful solar flares, great geomagnetic storm, speed of solar wind and from which active region the events was release.

As shown in figure 6.3, all type IV storms are found to be associated with very large solar flares. Predominantly, solar bursts events are accompanied with solar flares (from class C to M) producing major storms.

For type IV events preceded by type III burst, about half (9 events) of the events are found to be associated with major flare of X-class and M-class of solar flares. It clearly shown that 6 out of 9 events associated with great flare have sunspot that are directed toward Earth and the rest are not Earth directed or near to east or west limb. However, it can be seen that only 2 events with high speed of solar wind more than 500 km/s. Vice versa for type IV bursts only, it absolutely showing that 10 events associated with powerful solar flare have a slower solar wind speed which is below than 500 km/s.

Figure 1. Distribution of geomagnetic storm activity as a function of events: (above) type III preceding type IV burst with 20 events; (below) type IV only without type III with 17 events.
Table 2: Association of solar radio burst events with solar flares, geomagnetic storm, solar wind and active region.

| No. | Date       | Type IV With Type III | Type IV Only          | Date         | Solar Flare | Geomagnetic Storm Index | Solar Wind, km/s | Active Region | Solar Flare | Geomagnetic Storm Index | Solar Wind, km/s | Active Region |
|-----|------------|-----------------------|-----------------------|--------------|-------------|------------------------|------------------|--------------|-------------|------------------------|------------------|--------------|
| 1   | 13-Dec-06  | X3.4                  | 8                     | 2-Nov-08     | Class B     | 1                      | 401.2           | 1007         | Class B     | 1                      | 418.1           | 1009         |
| 2   | 3-Nov-08   | Class B               | 1                     | 11-Dec-08    | Class B     | 1                      | 400.4           | 1092         | M8.3        | 3                      | 340.9           | 1046         |
| 3   | 13-Feb-10  | C9.6                  | 4                     | 12-Feb-09    | Class B     | 4                      | 308.2           | 1048         | M1.6        | 5                      | 407             | 1158         |
| 4   | 13-Jun-10  | M1.0                  | 3                     | 12-Feb-10    | M3.2        | 1                      | 400.4           | 1079         | M8.3        | 3                      | 340.9           | 1046         |
| 5   | 1-Aug-10   | C3.2                  | 6                     | 16-Feb-11    | M1.6        | 5                      | 407             | 1158         | M8.3        | 3                      | 340.9           | 1046         |
| 6   | 5-Aug-10   | C1.3                  | 2                     | 3-Mar-11     | C5.4        | 4                      | 518.7           | 1093         | C5.4        | 4                      | 630.8           | 1164         |
| 7   | 14-Aug-10  | M4.2                  | 3                     | 7-Mar-11     | M3.7        | 4                      | 408.7           | 1099         | C5.4        | 4                      | 630.8           | 1164         |
| 8   | 18-Oct-10  | C2.5                  | 2                     | 30-May-11    | C7.0        | 3                      | 431.2           | 1112         | C7.0        | 3                      | 566.2           | 1226         |
| 9   | 19-Oct-10  | C1.3                  | 2                     | 2-Jun-11     | C3.7        | 5                      | 372.3           | 1149         | M2.5        | 3                      | 467.2           | 1226         |
| 10  | 22-Jan-11  | C2.4                  | 2                     | 7-Jun-11     | M2.5        | 3                      | 372.3           | 1149         | M2.5        | 3                      | 467.2           | 1226         |
| 11  | 14-Feb-11  | M2.2                  | 4                     | 29-Jun-11    | Class B     | 1                      | 400.9           | 1158         | Class B     | 1                      | 339.1           | 1242         |
| 12  | 15-Feb-11  | X2.2                  | 2                     | 2-Aug-11     | M1.4        | 4                      | 460.2           | 1158         | M1.4        | 4                      | 405.8           | 1261         |
| 13  | 24-Feb-11  | M3.5                  | 1                     | 22-Sep-11    | X1.4        | 2                      | 352.5           | 1163         | X1.4        | 2                      | 405             | 1302         |
| 14  | 1-Mar-11   | C6.0                  | 6                     | 23-Sep-11    | M1.9        | 2                      | 621.8           | 1164         | M1.9        | 2                      | 373.4           | 1302         |
| 15  | 3-Aug-11   | M6.0                  | 8                     | 24-Sep-11    | X1.9        | 8                      | 356             | 1261         | X1.9        | 8                      | 326.3           | 1302         |
| 16  | 9-Aug-11   | X6.9                  | 3                     | 25-Sep-11    | M7.4        | 7                      | 551.5           | 1263         | M7.4        | 7                      | 347             | 1302         |
| 17  | 11-Aug-11  | C6.2                  | 3                     | 25-Dec-11    | M4.0        | 1                      | 413.6           | 1263         | M4.0        | 1                      | 368.8           | 1387         |
| 18  | 1-Oct-11   | M1.2                  | 7                     | 1-Oct-11     | M1.2        | 7                      | 532.7           | 1305         | M1.2        | 7                      | 532.7           | 1305         |
| 19  | 9-Nov-11   | M1.1                  | 1                     | 9-Nov-11     | M1.1        | 1                      | 353.3           | 1343         | M1.1        | 1                      | 353.3           | 1343         |
| 20  | 13-Nov-11  | C2.6                  | 3                     | 13-Nov-11    | M1.1        | 1                      | 366.7           | 1347         | M1.1        | 1                      | 353.3           | 1343         |

Despite it is associated with great solar flare but still have lower geomagnetic index, this is might be from which active region releases and the solar wind speed. From which part of solar disc also take in consideration whether it was ejected from the sunspot that is directed to Earth or not. If not directed towards Earth, the energy that disturb Earth’s magnetic field is too small thus led to minor geomagnetic storm only. Compared to other energy that Earth directed which is, of course, will give extra amount of energy to magnetic field. As is known, the occurrence of solar radio burst type IV with geomagnetic storm have an outstanding relation. This was proven in this study, 12 events of the great geomagnetic storm (indexes from 5-8) associated with powerful flare. Out of 12 events, 3 events were C class flare and the remainder are M-class and X-class flare.
Conclusion

This clarify that, even though it has high solar flare ejected from the active region that Earth directed, but the solar wind speed is low thus do not have enough energy to eject the electron to the interplanetary medium to disturbing Earth’s magnetosphere. High speed winds bring geomagnetic storms while slow speed winds bring calm space weather. Other than that, there also have some events which have slow solar wind speed but have higher index of geomagnetic storm and great solar flare. This happen due to the accompanying CME to the events thus propelled more energy to the magnetic field. The association of CME in producing geomagnetic storm will be discussed in selected events.

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Acknowledgments
We are grateful to CALLISTO network, STEREO, LASCO, SDO/AIA, NOAA and SWPC make their data available online. This work was partially supported by the UITM internal BESTARI grant, 600-IRMI/DANA 5/3/BESTARI (067/2017) from the Kementerian Pengajian Tinggi Malaysia. Special thanks to the National Space Agency and the National Space Centre for giving us a site to set up this project and support this project. Solar burst monitoring is a project of cooperation between the Institute of Astronomy, ETH Zurich, and FHNW Windisch, Switzerland, Universiti Teknologi MARA and University of Malaya. This paper also used the NOAA Space Weather Prediction Centre (SWPC) for the sunspot, radio flux and solar flare data for comparison purpose. The research has made use of the National Space Centre Facility and a part of an initiative of the International Space Weather Initiative (ISWI) program.