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Correlation between Radio Flux (10.7 cm) and Sunspot Number Based on Statistical Properties

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ABSTRACT

Statistical properties of solar radio burst radio type II and III of this work will be highlighted. One of the best advantages of using the radio method is that it allows high quality images within an arc second resolution and different frequencies actually cover different layers of the solar atmosphere. Statistical studies of both bursts are required to obtain such observational constraints with sufficient statistical confidence. In the first part, the trend of both bursts from 2006-2011 is examined. We need to consider a few parameters such as a burst duration, drift rate, energy of the photon, and the structure of the burst. From (0.0 0.5) MHz/Sec, the data represent the highest slope with m = 1290.1685 km/MHz in average. In the range of (4.0 7.0) MHz/Sec, the range of CMEs velocity is less than 500km/Sec. The lowest CMEs velocity that can be observed is ~137 km/Sec. The relationship between both parameters is $F_{10.7\text{cm}} = 0.4568R + 73.8655$. This work presents the first step toward an analytical model of statistics of solar radio burst information of average events as something crucial to the acceleration mechanism.

Keywords**:** Sun; solar burst; radio region; solar flare; Coronal Mass Ejections (CMEs)

1. INTRODUCTION

The previous work gave an overview of the evolution and statistical properties of a solar radio burst type II and III from energy release high in the Sun, which heats plasma and accelerates particles and the corresponding response of the chromospheres [1-3]. One of the best advantages of using the radio method is that it allows high quality images within an arc second resolution and different frequencies actually cover different layers of the solar atmosphere [4,5]. Observations of solar radio burst by low spectral and spatial resolution instruments can provide only the light curve and a crude spectrum of the whole flares, as well as CMEs which may consist of many distinct sources with different characteristics [6-8]. Nevertheless, statistical studies of both bursts are required to obtain such observational constraints with sufficient statistical confidence. In this work, a sample of solar radio burst taken from the e-CALLISTO network was carefully selected which may provide some statistical information on solar radio emissions [9].

Statistical properties of solar radio burst radio type II and III of this work will be highlighted. It is necessary to stress once more that the preceding work is based on the current status of observations. In assembling an e-CALLISTO catalogue, the number of detections of both solar types II and III radio bursts was calculated [10,11]. As observed, solar flares and CMEs surveys are a good and significant method to study physical trends of both phenomena [12,13,14]. This project started since 2006 with 12 sites during that period.

2. RADIO OBSERVATION AND METHOD ANALYSIS

In radio observation, the CALLISTO spectrometer is designed and built to detect the intensity of radio emission at radio frequencies between 45-870 MHz [15]. The receiver system consists an antenna, a front end equipped with a low-noise amplifier (LNA) unit and a hybrid amplifier, and a back-end with units of a power combiner, a spectrum analyzer and a personal computer (PC) [16]. Due to the development of the technology, more advanced system was implemented to the system includes a tower-mounted preamplifier or low noise amplifier, additional antennas and a focal plane unit (FPU) with antenna polarization switching and noise calibration capabilities [17].

In the first part, the trend of both bursts from 2006-2011 is examined. Then, we decided to focus only in 2011 because of a few factors. First, the solar burst data in 2011 are much more relevant and accurate based on confirmation with 18 sites on e-CALLLISTO network. Second, the data are more consistent with NOAA data in X-ray region. Currently, until May 2013, there are 30 sites over the world which is using CALLISTO spectrometer to monitor solar activities in low frequency from 45 MHz till 870 MHz [18]. However, due to the interference, each site decided to focus only on the range with very minimum interference [19-24]. This is to avoid any irrelevant data. The database then will be uploaded automatically every 15 minutes. More information on the 18 sites e.g. ranges of frequency and duration of observations is given in Table 1.

Table 1. Ranges of frequency and duration of observations.

Site	**Latitude**	**Longitude**	**Minimum Frequency**	**Maximum frequency**	**Starting observation (UT)**	**End observation (UT)**	**Duration of observation**
Alaska	61.1822° N,	148.5569° W	45	870	0000 2330	230 2330	11hours 5 minutes
Almaty	43.2500° N,	76.9167° E	45	870	140	1130	9 hours 50 minutes
Blen7m	45°38′37′′ N	13° 52′ 34′′ E	45	870	715	1500	7 hours 45 minutes
Blensw	45°38′37′′ N	13° 52′ 34′′ E	5	90	715	1500	7 hours 45 minutes
Daro	25.26° N,	68.97° E	45	470	715	1530	8 hours 15 minutes
Gauri	25.47 N	85.318° E	45	410	230	930	7 hours
Humain	50.20° N	5.2500° E	45	400	845	1445	6 hours
Krim	3503'04" N	110°44'18" W	250	350	622	1136	5 hours 14 minutes
Malaysia	2° 48' 34.9848" N	E 101° 30' 14.7636"	150	400	0030	1230	12 hours
MRO	17.435 N	78.447 W	780	1450	723	1215	4 hours 52 minutes
MRTU	17.435 N	78.447 W	45	870	200	1345	11 hours 45 minutes
MRTV	17.435 N	78.447 W	45	870	200	1930	7 hours 30 minutes
Ooty	11.4090° N	76.6966° E	45	450	230	1200	9 hours 30 minutes
Osra	29.0 N	88.3 E	150	850	840	1230	3 hours 50 minutes
RCAG	40-02-19.8000 N	088-16-40.1000W	230	450	0015	900	8 hours 45 minutes
SSRT	149.8 E	30.30 S	45	450	200	600	4 hours
SWMC	51:47:07 N	3:21:25W	45	350	500	1430	9 hours
UNAM	99.18437E	19.31889 S	150	450	1300	2245	9 hours 45 minutes

3. RESULTS AND ANALYSIS

We need to consider a few parameter such as a burst duration, drift rate, energy of the photon, and the structure of the burst. The current conditions of space weather were taken from the space weather website provided by NASA and the images of the structure of sunspot on the Sun, data and other images revealed by SOHO Observatory, Solar Monitor, SWPC and CACTUS which also have a collaboration with NASA. Then we compare with the optical image.

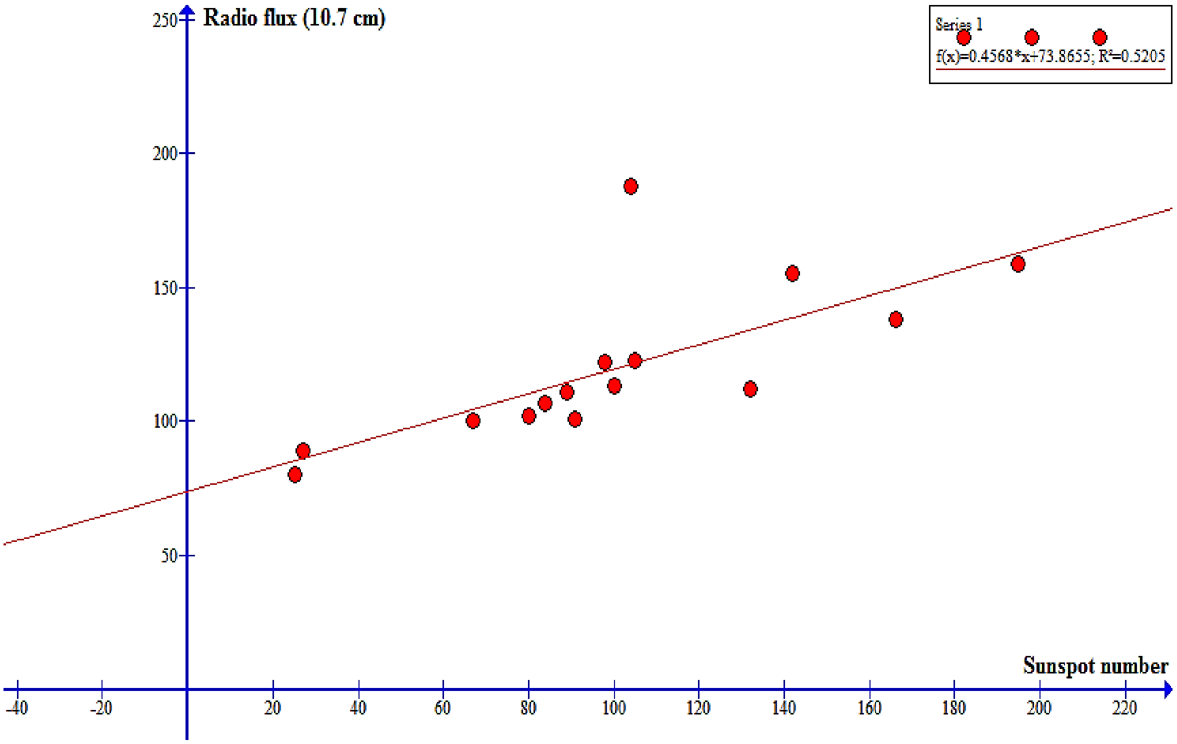

Figure 1. Correlation between Radio Flux (10.7 cm) and sunspot number.

Figure 1 shows the relationship between the 10.7 cm (2800 MHz) radio flux and the sunspot number. The two measures are moderately correlated (r = 0.72145, r2 = 0.5205). The relationship between both parameters in this selected data is:

$$F_{10.7\ cm} = 0.4568\ R + 73.8655$$

In this case, measurement of 10.7 cm solar flux taken from the NOAA is the data of the integrated emission at 10.7 cm wavelength from all sources present on the disc. Almost completely thermal in origin and directly related to the total amount of plasma trapped in the magnetic fields overlying the active regions. This is due to the amount of magnetic flux. A comparison made over more than one solar activity cycle shows that there is indeed a linear correlation between the 10.7 cm solar flux and the total photospheric magnetic flux in active regions. In conclusion, it can be construed that these two quantities are correlated at the

45.68% level. This result proves that there must be other factors that contribute to the CMEs events. Physical mechanisms of generation of CMEs still remain uncertain in many respects.

Subsequently, we then focus on SRBT II by looking at the basic parameter of this burst. Table 2 below shows the properties of SRBT II associated with solar wind parameter.

Table 2. Properties of solar radio burst type II associated with solar wind parameter.

Property	**Mean**	**Max**	**Min**
Starting frequency (MHz)	350.18	40	750
Ending frequency (MHz)	171.65	21	363
Solar wind Speed (Km/s)	441.535	304.1	698.3
Bandwidth (MHz)	78.53	19	387

Now, the calculation of the drift rate is determined from the starting and ending frequencies, and the time duration of type II bursts given by the following relation;

$$\frac{df}{dt} = \frac{(f_s - f_e)}{T_d}$$

where T_d is the time duration between the start and end. In this case, fs and fe are starting and ending frequencies, respectively.

Table 3. Bandwidth of solar radio burst type II.

High frequency (MHz)	**Low frequency (MHz)**	**Bandwidth (MHz)**	**Duration (Minutes)**
80	27	43	0:10:36
64	25	39	0:03:59
324	180	184	0:05:29
550	200	350	0:04:20
324	180	184	0:02:01

340	240	100	0:00:40
496	363	133	0:00:56
275	229	46	0:00:24
450	200	250	0:16:54
40	21	21	0:02:54
450	315	135	0:08:00
750	190	560	0:02:18
80	23	57	0:05:27
370	195	175	0:01:07
360	175	185	0:01:36
330	180	150	0:00:35

Here, the parameter will continue to be analyzed by considering a drift rate of SRBT II and correlate with solar wind speed and CMEs velocity. Following Table 4 below shows the measurement of drift rate and the correlation of this parameter with solar wind speed.

Table 4. Drift rate and solar wind speed and CMEs velocity measurement.

Bandwidth (MHz)	**Duration**	**Drift rate (MHz/second)**	**Solar Wind Speed (km/s)**	**CMEs velocity (km/s)**
43	0:10:36	0.067	317.2	138
39	0:03:59	0.1206	467.2	1822
184	0:05:29	0.1631	400.9	301
350	0:04:20	0.174	405	769
184	0:02:01	0.2465	467.2	425
100	0:00:40	0.282	356	599
133	0:00:56	0.5592	407	137
46	0:00:24	1.3462	325.2	446
250	0:16:54	1.5206	562.3	694

21	0:02:54	1.92	503.8	694
135	0:08:00	1.927	304.1	882.0
560	0:02:18	2.375	566.2	2309.0
57	0:05:27	2.5	698.3	1289.7
175	0:01:07	2.62	453.9	193
185	0:01:36	4.285	366.7	304
150	0:00:35	6.346	304.1	329

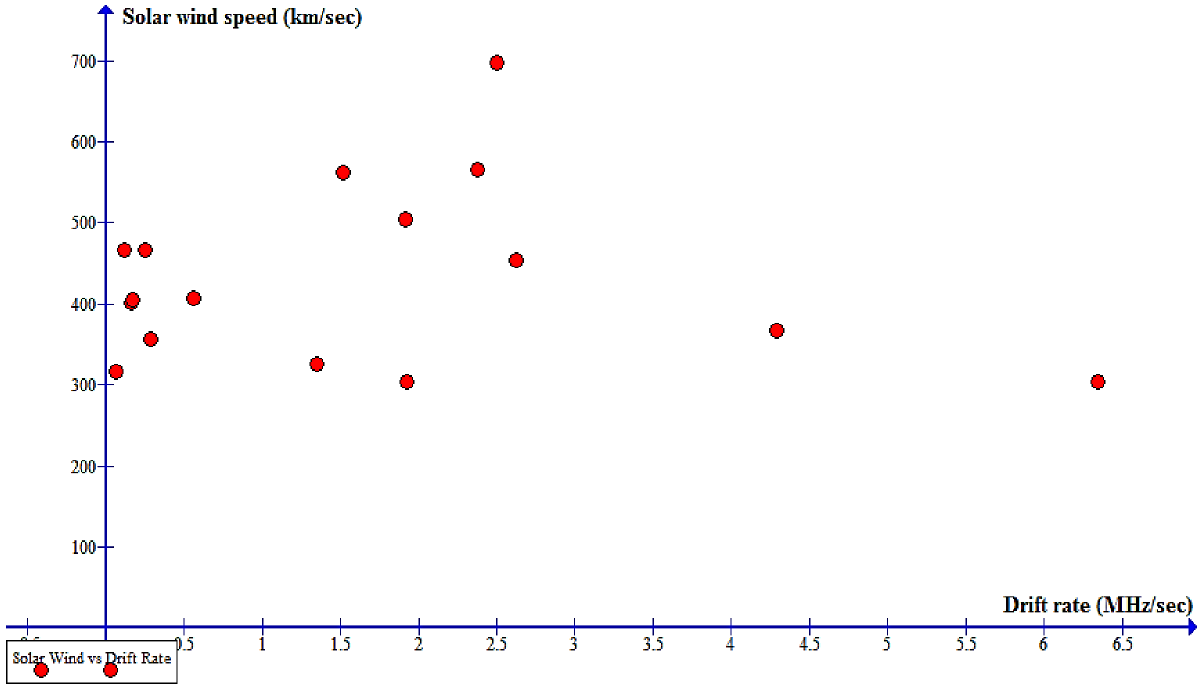

Figure 2. Correlation between solar wind speeds (kms-1) with drift rate (MHz/second).

To reliably determine reliably the solar wind parameter, the correlation of solar wind with SRBT II is then observed. The solar wind speed versus drift rate correlation was also suggested as a response to the inverse correlation between the saturation time of a wave-particle plasma instability originating the burst and the radiation time. Thus, there is no indicator at all that the drift rates of this burst contribute to the solar wind. It shows a very dynamic pattern and not consistent short-term periodicities. These results seem reasonable, as it seems that each event of CMEs is distributed at a very wide range of frequency. But since these values were obtained with a new method, it makes sense to inspect the measurement with an alternative well established X-ray measurement.

Now, focus will be on an analysis based on temporal coincidence and CMEs' velocity and frequency drift rates of type II radio bursts, respectively. The drift rate is based on CALLISTO data while an average of CMEs velocity is taken from the LASCO. Detailed results can be interpreted from Figure 3.

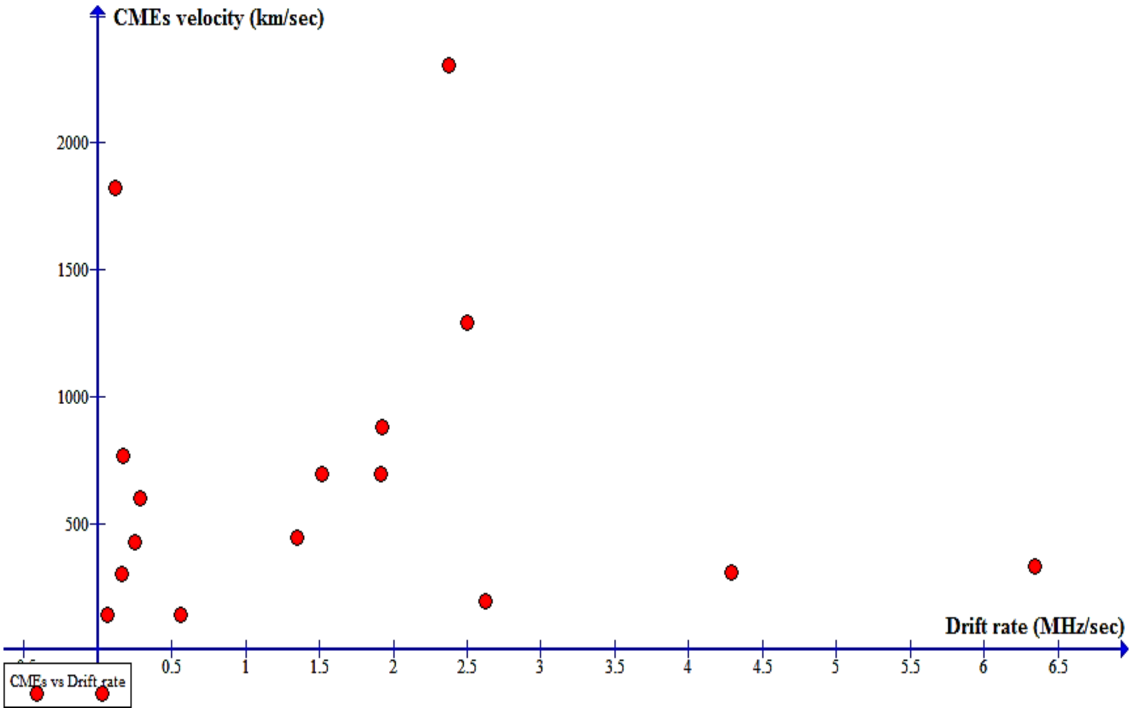

Figure 3. CMEs (km/sec) versus Drift rate (MHz/sec).

Although the distribution of the results might be dynamic, there are some clues from some data that shows the same pattern of slope. The results suggest that there are three (3) scenarios leading to metric type II solar radio burst excitation. The following are some observations:

1. From (0.0 – 0.5) MHz/Sec, the data represent the highest slope with *m* = 1290.1685 km/MHz in average.
2. It can clearly be observed that in the range of 0.5 MHz/sec –2.5 MHz/Sec, the distribution is considered as a moderate pattern with a slope value of *m* = 1162.7183 km/MHz.
3. In the range of (4.0 –7.0) MHz/Sec, the range of CMEs velocity is less than 500 km/Sec. In general, the increase of drift rate values means that the CMEs velocity decreases.
4. Out of 16 events, almost 11 events have a drift rate less than 2 MHz/sec.
5. There is one event where the velocity of CMEs exceeds more than 2000 km/Sec.
6. The lowest CMEs velocity that can be observed is ~137 km/Sec.

4. CONCLUDING REMARKS

This work presents the first step toward an analytical model of statistics of solar radio burst information of average events as something crucial to the acceleration mechanism. The study of solar burst has generated a great deal of activity in the field of solar physics. Long term observations potentially tell us the dynamic behaviour of the sun. The group of solar radio burst events has a larger mean ending frequency, which means that the kinetic energy is small, so the mean ending frequency is high and the duration is short. It should realized that the high sensitivity of observational data with the high time and frequency resolution will lead to the analysis of spectral fine structure of solar radio bursts. A possible future improvement would be obtained by considering the dynamic structure of each solar radio burst event.

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