Correlation Structure of Solar Radio Bursts in Accordance with Solar Activity

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Abstract: Sun is the nearest star that employs us an opportunity to study the behavior of celestial bodies and their influence on Earth's atmosphere. This paper investigates the dynamics of Solar Radio Bursts (SRB) with respect to their frequencies type II, type III and Mixed type in accord with Sun Spot Number (SSN) over a span of (1996-2010) base over monthly values. Data from National Oceanic and Atmospheric Administration (NOAA) Space Weather Centre were used in this study. This period covers one full and two partial solar cycles. The ionosphere plays a significant role in radio wave communication, therefore the critical frequency of F_2 layer (foF_2), Maximum electron density (N_mF_2) Plasma frequency (f_P) and Sudden Ionosphere Disturbance (SID) also been included. In various ionospheres quantifications, solar activity such as SSN and 10.7 cm radio flux were used. However SRB influence being considered as a separate variable has not been investigated. The relationship of SRB with Solar Cycle and a comparative study of the influence of these solar variables on ionosphere F_2 layer have investigated. The model equations are developed between those variables that have a significant relationship. These equations may be helpful to forecast perturbations in respect of the solar activity.

Keywords: Sun Spot Number, Ionosphere variables, Solar Cycle, Ionosphere perturbations, Exploratory Data Analysis.

INTRODUCTION

The natural source of energy is the Sun that helps how the life can be exist on Earth through radiations, which was originally identified as visible sunlight, but solar electromagnetic radiation that has both electrical and magnetic properties, wrapped infrared, visible and UV light. Sometimes the sun appears as a quiet star, but sometimes it's more active from the farthest distance. The changing in their activities is random and therefore there is a need to quantify them. There is a gradual change in size and energy of those activities and they may stay a very long time [1].

The data investigated under this study is based over monthly values because the past research identified that solar source contribute more with respect to monthly or yearly variation [2].

Solar radio bursts provides important information regarding the Sun mechanism. It is an ideal indicator on investigating acceleration processes which are responsible for excited velocities of energetic particles and magnetic plasma clouds. As the solar activity increases, number of solar flares, Coronal Mass Ejections, solar radio bursts events also increases. Each cycle has a different trend for solar radio burst [3].

Different types of solar radio bursts are generated during the changes of solar activity, especially type I, II and III. They are most commonly generated type. The plasma frequency is comparable with the initial frequencies of type II and type I storm, but the properties of type I and II are not similar from each other. Type I storm is associated with the type IV burst; both are detected and act as surrounded electron inside the rings, throughout rising together [4].

The type II burst is generally called slow frequency drift bursts, they have a very high intensity and they are internally associated with flares, proton emission and magneto hydrodynamic (MHD) shock within the range of 20-150 MHz. The range of type II frequency lies within 60 to 90 MHz [5].

Type III burst creates due to fast accelerating particles called as fast drifting radio burst, throughout the contribution of a flare's phenomena, then they are caused by the electron's beam, which are circulating sideways of the lines of magnetic field and offer expanded towards Langmuir waves, that's this type is also called fast drifting burst. They designate the rapid acceleration of particle throughout flare phenomena [6].

The F-Layer is the top most important layer which is involving in ionization and disturbs our communication system, when it is interrupted, is known as "Appleton Layer". This layer comprise by of two layers, which are F_1 and F_2 layer, the F_2 layer has desperately disturb from some solar changes like sunspot number (SSN). During the day time both layers are extended, but in the night both are combined together in form of a single layer. During the day-time and night-time, the range of

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electron density of F_2layer is 10^6-3×10^6 electron/cm^3 and 10^4-10^6 electron/cm^3. The electron number density is related to the critical frequency of F_2 layer by the following formula, $N_mF_2 = 1.24 \times 10^4(f_0F_2)^2$ where N_mF_2 is the electron number density in electron/cm^3 and is f_0F_2 is the critical frequency of F_2 layer in MHz [7].

Due to the rapid growth or reduction in frequency of ionization in Solar Radio Burst (SRB) disturbs the critical frequency of F_2 layer [8]. The local plasma frequency is calculated by the formula, $f_P = 9000\sqrt{n_e}$ where f_P is the plasma frequency in MHz and n_e is the electron density in electron /cm^3 [9].

The two major types of phenomena associated with solar flare are the immediate effects and the delayed effects. The immediate effects occur simultaneously with the visible flare and consist of phenomena known as solar radio bursts and sudden ionosphere disturbances. Both are interrelated to each other, but there are no any theory or scientifically prove their direct relation [10].

Cellular phones and their stations can be easily affected from strong solar radio bursts, especially when there are strong radio bursts during sunrise and sunset [11-12].

METHODOLOGY

The data used in this study was obtained from National Oceanic and Atmospheric Administration (NOAA) Space Weather Centre for a period of (1996-2010). After examining the whole length of data the investigation will cover for minima (1996-1997) and maxima (2001-2002). The equinoxes are the month of March and September and Solstices are the month of June and December during (1996-2010). The analysis has been accomplished by using the software Minitab 17.

Regression analysis is one of the most commonly used statistical techniques which involves identifying and evaluating the relationship between a dependent variable and one or more independent variables, which are also called predictor or explanatory variables [13].

The reliability of the model, check by finding coefficient of determination (R-square) R^2 = SSR/SST

Where

SSR = regression sum of squares and ***SST*** = total sum of squares

The Pearson Product Moment coefficient of correlation employs there to find the relationship between different variables

$$r = SS_{XY} / \sqrt{SS_X SS_Y}$$

Where,

$$SS_{XY} = \sum_{i=1}^{n} x_i^2 y_i^2 - \frac{1}{n}\left(\sum_1^n x_i\right)^2 \left(\sum_1^n y_i\right)^2$$

$$SS_X = \sum_{i=1}^{n} x_i^2 - \frac{1}{n}\left(\sum_1^n x_i\right)^2$$

$$SS_Y = \sum_{i=1}^{n} y_i^2 - \frac{1}{n}\left(\sum_1^n y_i\right)^2$$

SS is the sum of the squares of the desired variables [14-15].

RESULTS AND DISCUSION

Distinct characteristics were observed in respect of the two solar indices; the SRB and the SSN with four ionosphere variables; the critical frequency, the maximum electron density, the sudden ionosphere disturbance and the plasma frequency of F2 layer.

The existence of a sunspot or a group of sunspots is a necessary condition for the generation of noise storms [16]. In view of this close association between the two it has been observed that highest correlation of 45.0% is associated with SSN and mixed type radio bursts during the complete data epoch (1996-2010). This mixed type radio bursts also shows a highest correlation with the four ionosphere variables during this period as compare to the other two types of radio bursts. After distributing the data into four different categories of sunspot maxima (2001-2002), minima (1996-1997), solstices and equinoxes it has been found that SRB III has highest correlation with SSN at equinoxes. A non-linear relationship found between SSN and all three types of SRB. There coefficients of determination are not too strong. The critical frequency, maximum electron density and plasma frequency are correlated much better with the SSN rather than SRB. All these three ionosphere variables are strongly correlated with SSN at solstices. These are also much reliable than others because of their strong coefficient of determination (R^2). During (1996-2010) SID has small correlation with both SSN and SRB but comparatively it is higher with SSN. Its highest

Table 1: Model Equations Between SSN and SRB

	Regression equation	R^2	P-value
	SSN vs SRB		
Type III	$y = 10.24 + 0.0268x – 0.000002x^2$	31.0	P = 0.000
Type II	$y = 6.689 + 0.01479x – 0.000001x^2$	22.8	P = 0.000
Mixed type	$y = -6.864 + 0.05512x – 0.000010x^2$	32.0	P = 0.000

Table 2: Model Equations between SRB and Ionosphere Variables

	Regression equation	R^2	P-value
	f_0F_2 *vs SRB*		
Type III	$y = 49.38 + 0.009159x – 0.000001x^2$	23.2	P = 0.000
Type II	$y = 55.89 + 0.001275x$	7.4	P = 0.000
Mixed type	$y = 43.58 + 0.01887x – 0.000003x^2$	24.0	P = 0.000
	SID vs SRB		
Type III	NIL	-	P = 0.132
Type II	$y = 103.5 + 0.01203x$	5.0	P = 0.003
Mixed type	$y = 32.89 + 0.1274x – 0.000021x^2$	8.8	P = 0.020
	N_mF_2 *vs SRB*		
Type III	$y = 4.50 + 0.00032x$	4.5	P = 0.004
Type II	$y = 4.10 + 0.00021x$	7.1	P = 0.000
Mixed type	$y = 2.158 + 0.003006x – 0.000001x^2$	21.3	P = 0.000
	f_p *vs SRB*		
Type III	$y = 49.46 + 0.00930x – 0.000001x^2$	23.5	P = 0.000
Type II	$y = 56.01 + 0.00129x$	7.4	P = 0.000
Mixed type	$y = 43.58 + 0.01907x – 0.000003x^2$	23.9	P = 0.000

Table 3: Model Equations between SSN and Ionosphere Variables

	Regression equation	R^2	P-value
SSN vs. SID	$y = 20.51 + 0.210x – 0.0001x^2$	15.4	P = 0.000
SSN vs. foF2	$y = -92.84 + 2.256x$	78.9	P = 0.000
SSN vs. N_mF_2	$y = -51.38 + 25.28x – 0.8898x^2$	81.7	P = 0.000
SSN vs. f_P	$y = -91.59 + 2.230x$	78.7	P = 0.000

correlation was 78.0 % with type III radio bursts and 65.3% with SSN. Both these are being found at sunspot minima. The correlation of SRB II is mostly insignificant as confirm by its P- value which is higher than (0.05), the level of significance. However, its correlation is 57.3% with SID at the equinoxes.

Observations of low frequency solar type III radio bursts has long been of interest as it associated from the ejection of plasma oscillations [17]. The investigation there found that mixed type of SRB are more closely related to SSN rather than type II or III during the total data length of (1996-2010). However, the difference in their correlation values is not too spacious. At equinoxes radio burst III has highest correlation of 63.9% with SSN. It also strongly correlated with plasma frequency (f_P), electron density

Table 4: Correlation between Three Types of Solar Radio Burst with Different Variables

	SSN vs SRB									
	Maxima		Minima		Solstices		Equinox		1996-2010	
	r	P	r	P	r	P	r	P	r	P
Type III	41.6	0.043	61.5	0.002	9.3	0.624	63.9	0.000	23.2	0.002
Type II	36.0	0.084	-27.9	0.187	25.6	0.173	46.0	0.011	33.8	0.000
Mixed type	50.9	0.011	50.0	0.013	25.7	0.171	59.5	0.001	45.0	0.000
	f_0F_2 vs SRB									
Type III	21.3	0.317	24.0	0.270	12.8	0.500	4.7	0.008	21.4	0.004
Type II	0.2	0.994	-13.9	0.517	30.9	0.097	31.1	0.094	27.2	0.000
Mixed type	28.5	0.177	48.9	0.015	24.0	0.201	46.9	0.009	38.6	0.000
	SID vs SRB									
Type III	59.1	0.002	78.0	0.000	3.7	0.846	35.4	0.055	11.3	0.131
Type II	30.8	0.143	-1.3	0.951	0.9	0.963	57.3	0.001	22.3	0.003
Mixed type	18.2	0.000	67.0	0.000	21.7	0.250	28.9	0.121	24.5	0.001
	N_mF_2 vs SRB									
Type III	22.3	0.295	22.6	0.300	11.7	0.538	46.0	0.011	21.2	0.004
Type II	1.0	0.964	-11.4	0.595	33.0	0.075	30.0	0.107	26.6	0.000
Mixed type	28.3	0.180	49.8	0.013	22.2	0.238	45.8	0.011	37.3	0.000
	f_p vs SRB									
Type III	27.8	0.189	24.0	0.270	12.8	0.499	47.7	0.008	21.7	0.003
Type II	0.7	0.972	-13.9	0.518	30.9	0.096	31.1	0.094	27.3	0.000
Mixed type	27.8	0.189	10.8	0.616	24.1	0.200	46.9	0.009	38.6	0.000

Table 5: Correlation between SSN and Different Ionosphere Variables

	Maxima		Minima		Solstices		Equinox		1996-2010	
	r	P	r	P	r	P	r	P	r	P
SSN vs. SID	56.5	0.004	65.3	0.001	27.7	0.138	33.8	0.068	29.1	0.000
SSN vs. foF2	42.2	0.040	28.8	0.173	90.6	0.000	90.4	0.000	88.8	0.000
SSN vs. N_mF_2	41.5	0.044	28.4	0.179	89.1	0.000	88.9	0.000	87.4	0.000
SSN vs. f_P	44.5	0.029	28.8	0.173	90.6	0.000	90.5	0.000	88.7	0.000

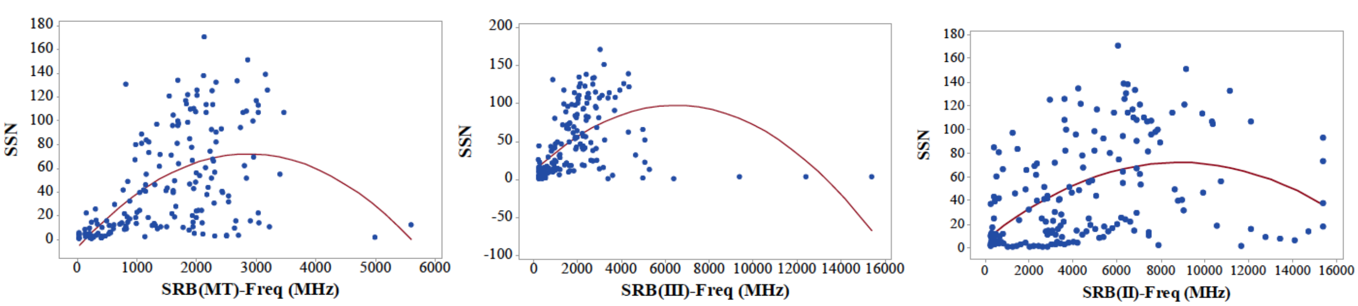

Figure 1: Non-Linear behavior of three types of SRB with SSN.

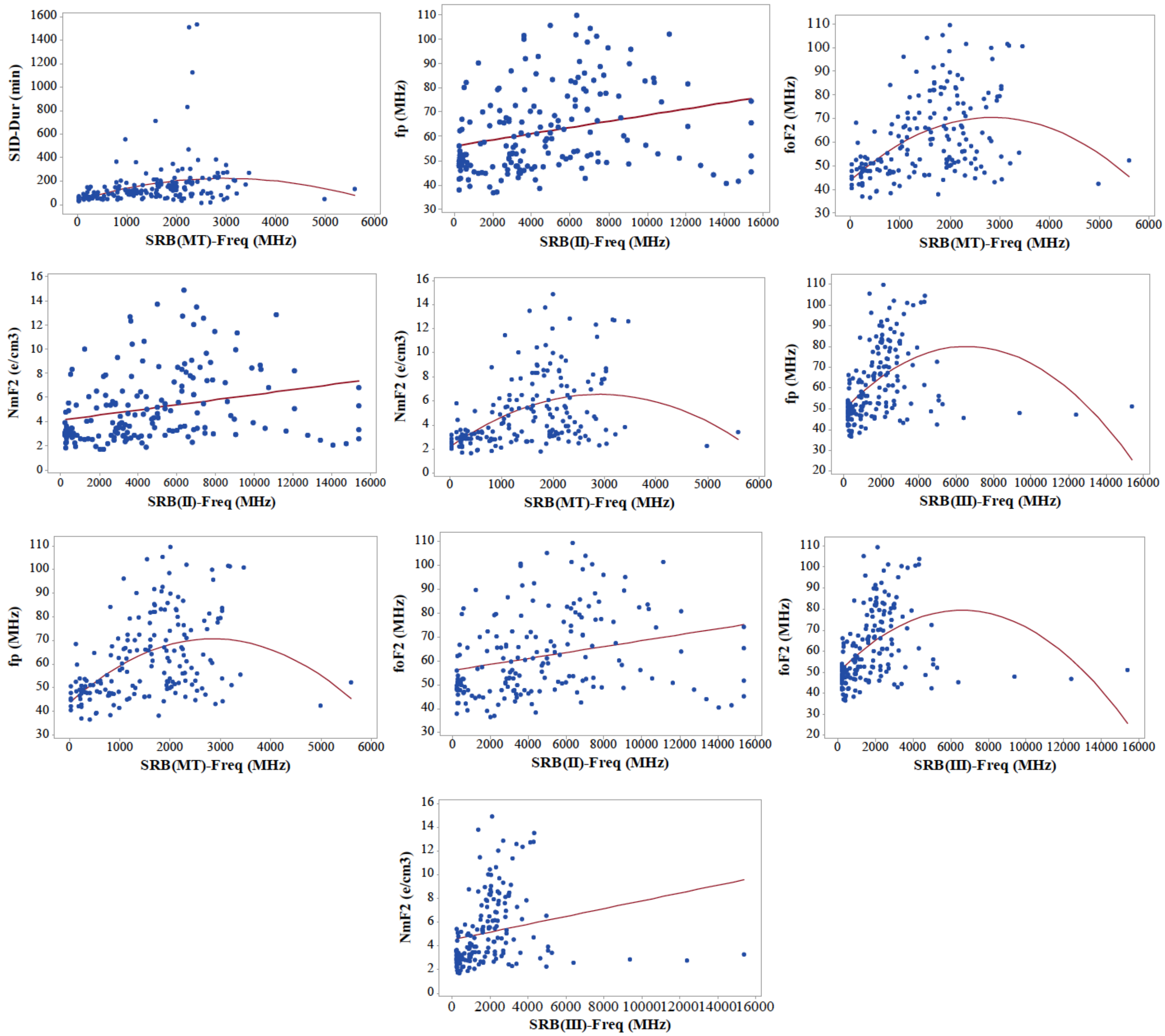

Figure 2: Linear and Non-Linear behavior of three types of SRB with four ionosphere variables.

(N_mF_2) and SSN at equinoxes but it has no influence on critical frequency of F_2 layer (foF_2).

Type II radio burst has a linear dependence with all four variables of ionosphere whereas type III radio burst has no correlation with SID and have a linear relationship with electron density (N_mF_2) only. Among the four ionosphere variables SID and electron density (N_mF_2) follow non-linear behavior with SSN.

CONCLUSIONS

The trend of ionosphere variables with respect to the solar cycle and the relationship of three types of radio bursts have been observed. It has been found that the level of correlation varies among all these variables during different time periods. Firstly by examining the complete solar cycle it has been observed that the mixed type radio burst may consider as the signature of SSN because of its maximum positive correlation. All the four ionosphere variables have high correlation with SSN rather than SRB. Type III radio bursts have smallest correlation with SSN and all the four ionosphere variables whereas the mixed type have the greatest. Second by examining the different epoch of the solar cycle the type III radio bursts have strong association with SSN at equinoxes. It also strongly correlated with SID at solar maxima and minima. Type II radio bursts have highest correlation with SID at equinoxes only.

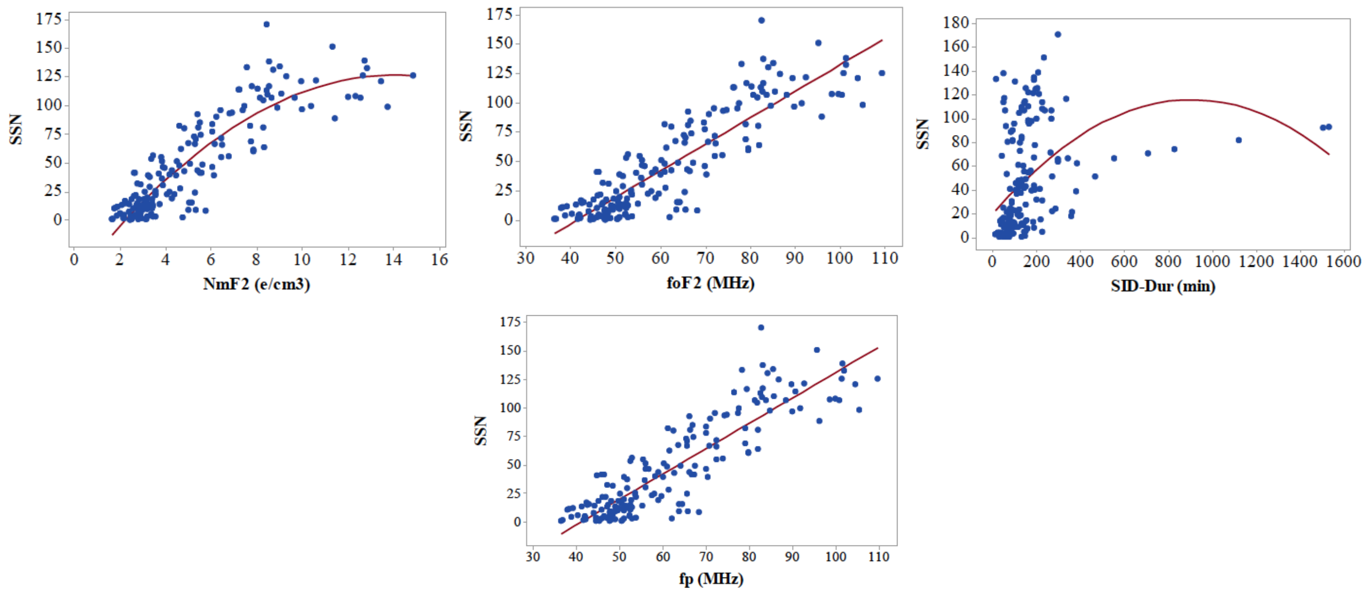

Figure 3: Linear and Non-linear behaviour of SSN with four ionosphere variables.

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