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Research Article

Appraisal of Solar Activity at Pakistan Atmospheric Regions

Saifuddin Ahmed Jilani[1], and M. Ayub Khan Yousuf Zai[2*]

[1]Department of Physics and Institute of Space & Planetary Astrophysics (ISPA), University of Karachi, Karachi-75270, Pakistan
[2]Department of Applied Physics, Solar- Terrestrial and Atmospherics Research Center and Institute of Space & Planetary Astrophysics (ISPA), University Karachi, Karachi-75270, Pakistan

Abstract: This study presents an indigenous work to investigate periodicity in Solar Flare Duration (SFD) at Pakistan atmospherics region over a period of 1979-2006. The disorderly behavior of solar flare generates solar protons which often associated with gradual flares and Coronal Mass Ejection (CME). Their adverse effects are on space weather and hence orbiting satellites and radio wave communication system. Therefore a better understanding of periodic activities in the sun is useful for the prediction of the effects of solar activity on Earth. We revealed the first peak periodicity in the mixed series of Solar Flare Duration (SFD) and implemented a test of periodic ordinate and confidence interval to substantiate the results. Gradual flares are undesirable to the terrestrial climate so we separate the series of impulsive and gradual flares from the mixed series and revealed their periodic behavior as well. This study intended to propose that periodic behavior in the solar flare duration may be one of the important aspects of solar flare activity.

Keywords: Solar flare duration (SFD), spectral analysis, fast fourier transform (FFT), mixed series of flares, gradual flares, impulsive flares

1. INTRODUCTION

Solar flares were discovered by C. Carrington and R. Hodgson on September 1, 1859. They are closely related to the Sun's magnetic field and occur in the active region of the solar atmosphere that superimposes sunspots [1].

The Sun's turbulent magnetic fields provide the fuel of flares. The swift release of energy in a flare results from a process called reconnection, whereby oppositely directed magnetic field lines come close together and partially annihilate each other [2]. Gradual flares are the long duration flares that lasting more than an hour and are associated with Coronal Mass Ejection (CME) [3]. These are the streams of solar particles and have numerous adverse effects on the terrestrial climate.

Physical origins of solar cycles are not known. They can be the internal property of the Sun as a star and its dynamo action as mostly believed now. Further the planetary influences and interstellar causes may contribute their effects as well [4-5]. The largest flares called CME, pose a potential threat to space travelers and may disrupt Earth communications [6]. CMEs are also the cause of geomagnetic storms that may initiate also in quiet parts of the Sun, without any association of solar flares. But it is misleading to jump to a conclusion, that the flares are not important any more in solar terrestrial relations. Flares are excellent indicators of coronal storms and actually indicate the strongest, fastest and most energetic disturbance coming from Sun [7]. Intense radiation from solar flares can change the electrical properties of our atmosphere; partially or totally black-out of radio wave communication systems. Friction can develop between the expanded atmosphere and satellite travelling in it, altering their orbit that drags them into outer space or down to earth [8].

2. METHODOLOGY

This evaluation based on two aspects of solar flares that are termed as impulsive and gradual

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*Corresponding author: M. Ayub Khan Yousuf Zai; Email: ayubzai@yahoo.com

flares in addition to their mixed series. By using spectral techniques, it is possible to look insight into different types of signals that are superimposed with each other. The spectral technique termed as Periodogram has been implemented for detecting the hidden periodicities in terms of their frequency and time contents. The results are analyzed by applying confidence interval to the peaks of these spectral estimates and by a test of periodic ordinates named as Fisher test.

The periodogram was introduced by Shuster in 1898 for studying the periodicities in the sunspot series. Any stationary time series is actually be the random superposition of sines and cosines oscillating at various frequencies and periodogram may be given us an idea of variance components associated with each frequency. This could be used to identify important harmonic components in time series data [9-11].

The period gram is defined by,

$$I(w) = \frac{2}{N}\{(\sum_{t=1}^{N} X_i Coswt)^2 + (\sum_{t=1}^{N} X_i Sinwt)^2\} \quad (1)$$

The function $I(w)$ is then computed for,

$$w_i = \frac{2\pi p}{N} \text{ --- (2); } \quad p = 0,1,2,----(N|2) \quad (2)$$

By searching the squared amplitudes for large values we can thus locate the approximate values of the true frequencies (w_i) [12].

For strong periodic components, the periodogram values corresponding or near to those frequencies will be large whereas the corresponding values of the periodogram will be small for periodic components not present in the data.

The amplitude of the pth harmonic is

$$R_p = \sqrt{a_p^2 + b_p^2} \quad (3)$$

The phase of the pth harmonic is

$$\varphi_p = \tan^{-1}(b_p / a_p) \quad (4)$$

The corresponding time lag for the pth component is

$$t_p = \frac{\theta_p}{2\pi f_p} \quad (5)$$

The Fourier transform determine the energy distribution of a time series so there is need to find its Fourier transform. This determines the coefficients in the Fourier series or evenly the amplitudes and phase lags [13].

An approximate 100(1−α) % confidence interval for the spectral density function would be of the form

$$\frac{v\hat{f}(\omega)}{\chi^2_{v,\alpha/2}} \text{ to } \frac{v\hat{f}(\omega)}{\chi^2_{v,1-\alpha/2}} \quad (6)$$

The degree of freedom for the Hamming window is 2.50 (N/M) respectively. A useful rough guide is to choose M to be about $2\sqrt{N}$. A window minimize the side-lobes and maximizes (concentrates) the energy near the frequency of interest in the main lobe [12, 14].

3. RESULTS AND DISCUSSION

3.1. Test of Non-stationarity

Spectral analysis is only appropriate for stationary time-series data. In order to detect non-stationary behavior, spectral analysis may perform on the originally observed series. Trend in data may detectable by a peak in the spectral density function at zero frequency [11, 15]. The spectral density function in Fig. 1-3 identified the peak in mixed series of flares at a frequency of 0.0123 whereas for impulsive and gradual flares these are 0.0056 and 0.0068 respectively. As these values are not exactly equal to zero, therefore it may consider that there is no need to implement the methods of removing the trend.

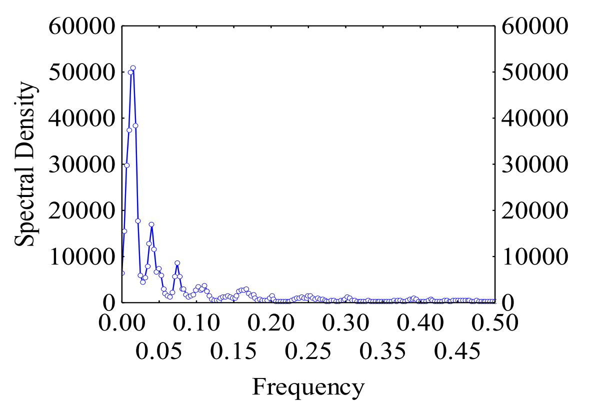

Fig. 1. Spectral Density for mixed series of flares.

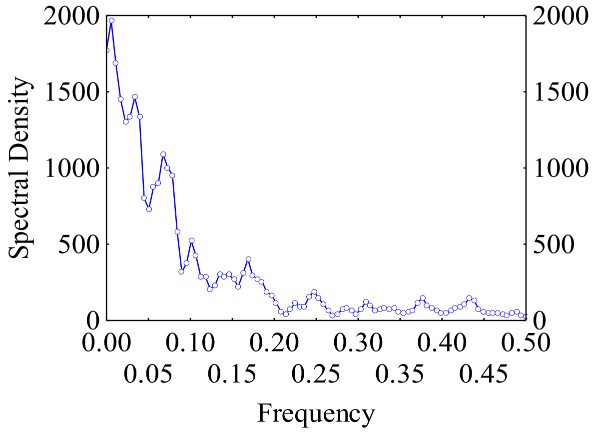

Fig. 2. Spectral Density for impulsive series of flares.

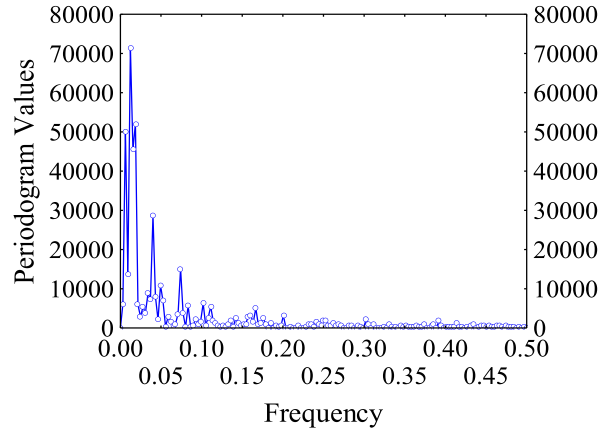

Fig. 4. Periodogram for the mixed series of SFD in frequency domain.

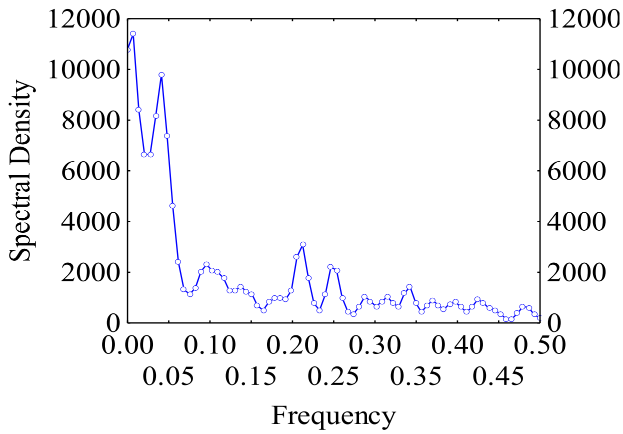

Fig. 3. Spectral Density for gradual series of flares.

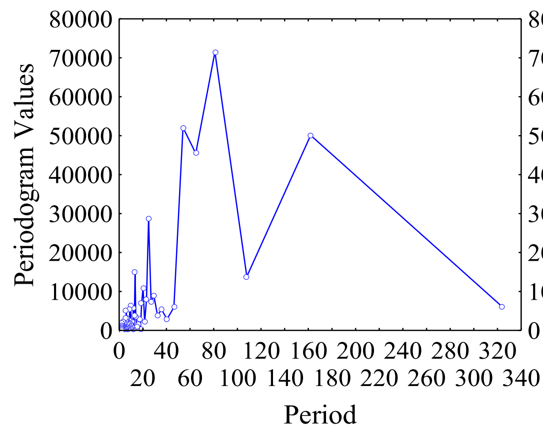

Fig. 5. Periodogram for the mixed series of SFD in time domain.

3.2. Estimation of Highest Frequency and Corresponding Periods

From periodogram analysis, highest peaks have been detected both in frequency and time domain. Fig. 4-9 depict the periodicities in mixed, impulsive and gradual series of flares. The periodicity in each of the mixed, impulsive and gradual series identified respectively as 81, 178 and 146 months per cycles. In addition to the basic periodicities identified above, there are well-defined peaks corresponding to periods of 54, 162, and 64.8 for the mixed series of flares, 25.4, 14.8, 59.3 for the impulsive phase and 24.3, 48.6, 18.2 for gradual phase.

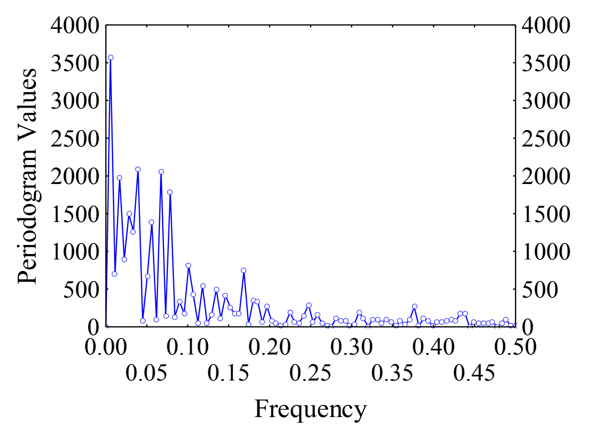

Fig. 6. Periodogram for the series of impulsive flares in frequency domain.

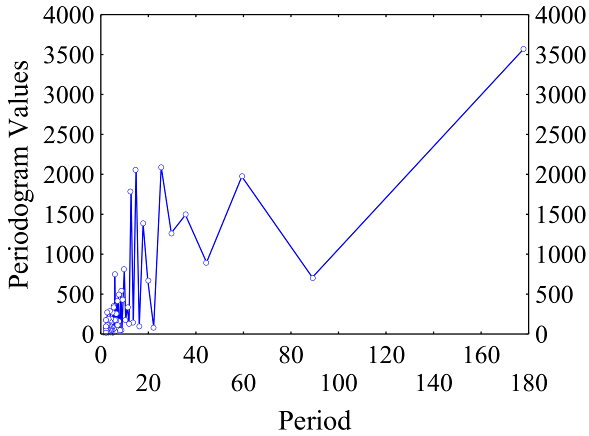

Fig. 7. Periodogram for the series of impulsive flares in time domain.

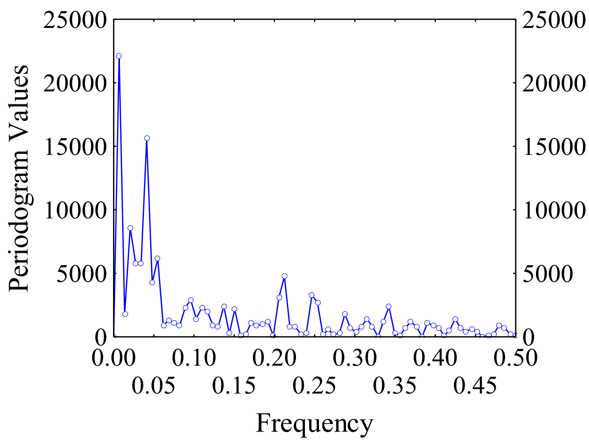

Fig. 8. Periodogram for the series of gradual flares in frequency domain.

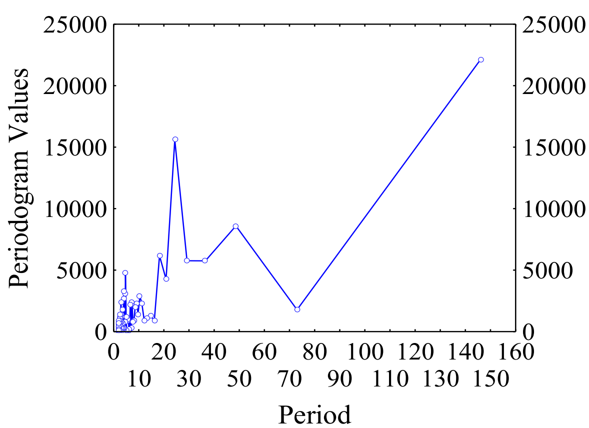

Fig. 9. Periodogram for the series of gradual flares in time domain.

3.3. Confidence Intervals for the Spectrum

A 95% confidence interval for the first highest peaks in the data series of SFD has been evaluated using Hamming window as mentioned in Table 1.

Table 1. First highest peak identified by periodogram.

Data Series	$\hat{f}(\omega)$	T	C.I (H.W)
SFD-Mixed	0.0123	81	0.0074 - 0.0242
SFD-Imp.	0.0056	178	0.0031 - 0.0125
SFD-Grad	0.0068	146	0.0037 - 0.0162

C.I. = Confidence Interval
H.W. = Hamming Window

3.4. Test for Periodic Ordinates

It may possible that peaks in the periodogram may not represent true periodicity in the given data series because of the random fluctuations in the error term. In such cases, it is suitable to apply certain tests to find the stability of the periodogram.

Fisher's Test: Fisher (1929) derived an exact test for max (I_p) based on the test statistic

$$g = \frac{\max(I_p)}{\sum_{p=1}^{N/2} I_p} \quad \text{------------- (7)}$$

known as 'Fisher's g statistic' [8].

The critical values for the Fisher test of significance for periodogram analysis at α = 5 % and N = 160; $g' = 0.08997$; N = 165; $g' = 0.08811$ N = 500; $g' = 0.03368$

For all of the three series the Fisher's g statistic is greater than their critical values, confirms the significance of their peak frequency and therefore the periodicity obtained by the periodogram. The test statistic is illustrated in Table 2.

Table 2. Fisher's g statistic for verifying accuracy of highest peak identified by periodogram.

Data Series	$\max(I_p)$	$\sum_{p=1}^{N/2} I_p$	g *statistic*
SFD-Mixed	$I_{0.0123} = 71512.9$	$\sum_{p=1}^{162} I_p = 471501.1$	0.1516
SFD-Imp.	$I_{0.0056} = 3572.2$	$\sum_{p=1}^{89} I_p = 28547.6$	0.1251
SFD-Grad	$I_{0.0068} = 22115.2$	$\sum_{p=1}^{73} I_p = 135412.9$	0.1633

3.5. Spectral Energy Estimates

The amplitudes of the Fourier coefficients define a periodogram that give the contribution of each oscillatory component in the total energy of the observed signal [13-15]. The phase angle that gives the relative 'lag' of the component and the corresponding time lag are illustrated in Table 3.

Table 3. Periodogram values with their amplitude, phase and time lag.

Data Series	$I_{p(w)}$	p	R_p	φ_p	t_p
SFD-Mixed	71512.99	4	21.0	0.65	8.44
SFD-Imp.	3572.2	1	6.33	0.197	5.59
SFD-Grad	22115.2	1	17.40	0.165	3.83

R_p = Amplitude φ_p = Phase t_p = time lag

4. CONCLUSIONS

This study of periodic variations in solar activity is sufficient for predicting future activity levels. Strongest amplitude is revealed in solar flare activity according to their duration. Through periodogram we define the highest peak and highest spectral energy at that portion of the time series. The direct impact of solar variability in accordance with the solar flare duration (SFD) becomes more pronounced in mixed series and less pronounced in impulsive and gradual phases of flares may be due to their partially non-stationary behavior. The periodicities identified in these series are more significant by investigating a long-term modulation of solar activity. In addition to the sunspot cycle, the cycles of solar flare duration are also be one of the manifestation of solar activity, is driven by the variations in the magnetic field.

5. ACKNOWLEDGEMENTS

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