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Research Article

Power Spectrum Analysis In Search For Periodicities In Solar Irradiance Time Series Data From Erbs

K. M. Hossain[1], *, D. N. Ghosh[2], K. Ghosh[3] and A. K. Bhattacharya[4]

[1]*Dpt of Electronics and Instrumentation Engineering, Dr. B.C. Roy Engineering College, Jemua Road, Fuljhore, Durgapur-713 206, India,*
[2]*Dpt of Mathematics, Dr. B.C. Roy Engineering College, Jemua Road, Fuljhore, Durgapur-713 206*
[3]*Dpt of Mathematics, University Institute of Technology, University of Burdwan, Golapbag (North), Burdwan-713 104, India,*
[4]*Dpt of Electronics & Communication, National Institute of Technology, Mahatma Gandhi Avenue, Durgapur-713209, India,*

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Abstract

In the present paper we have analyzed the solar irradiance data from the Earth Radiation Budget Satellite (ERBS) during the time period from October 15, 1984 to October 15, 2003 to detect the corresponding periods, if any with relevant scores (confidence). Power spectrum of the denoised signal has been obtained using FFT in order to search for its periodicities. Present calculation reveals strong periods around 9.08-9.35, 13.53-14.03, 27.50-28.17, 30.26, 35.99-36.37, 51.14-51.52, 68.27-68.60, 101.15, 124.85, 150.63-153.98, 659.90, 729.37, 1259.82, 3464.50 and 4619.33 days. We also got some weak periods around 46.19, 72.55, 82.49, 137.21-139.98, 395.94, 407.59 and 1979.71 days.

Keywords: FFT, Power Spectrum, periodicities, scores, Solar Irradiance data

1. Introduction

Total Solar Irradiance (TSI) is defined as the electromagnetic radiant energy emitted by the sun over all wavelengths that falls each second on 1 square meter outside the earth's atmosphere. Solar irradiance refers to electromagnetic radiation in the spectral range of approximately 1–9ft (0.3–3m), where the shortest wavelengths are in the ultraviolet region of the spectrum, the intermediate wavelengths in the visible region, and the longer wavelengths are in the near infrared. Total Solar Irradiance indicates the solar flux integrated over all wavelengths to include the contributions from ultraviolet, visible and infrared radiation.

The solar irradiance is been monitored with absolute radiometers since November 1978, on board six spacecraft (Nimbus-7, SMM, UARS, ERBS, EURECA, and SOHO), outside the terrestrial atmosphere. Before measuring it from space, this quantity was thought to be constant, because the precision of the ground-based instruments at that time was not high enough to detect small variation. It consequently earned the name of “solar constant”, which had a value of only 1,353 W/m^2. But from the data sent by the mentioned spacecraft it has been revealed that the solar irradiance varies about a small fraction of 0.1% over solar cycle being higher during maximum solar activity conditions. [1]

A major part of the Solar Irradiance variation is due to the combined effect of the sunspots blocking and the intensification due to bright faculae and plages, with a slight dominance of the bright features effect during the 11-year solar cycle maximum. Solar Irradiance variation within solar cycle is thought to be due to the changing emission of bright magnetic elements, including faculae and the magnetic network. [2]

The Solar Irradiance variation is very important for the understanding of solar internal structure and the solar terrestrial relationships. The radiative outputs of the sun establish the earth’s radiation environment and influence its temperature and atmosphere. It has been indicated that small persistent variation in energy flux may play an important role in climate changes. [2]

It has been recognized that the variation of the solar irradiance data obtained by the Earth Radiation Budget Satellite (ERBS) during the time period from October 15, 1984 to October 15, 2003 [3] has anti-persistent nature and thus it may have multi-periodicity [4]. In this paper we will try to identify the possible periods of this solar irradiance data and calculate their scores which are analogous to statistical confidence levels. The prerequisite for this is to smoothening and filtering the data to remove the circumstantial errors (which may creep in due to change in environment, or systematic error which is due to factors inherent in the manufacture of the measuring instrument arising out of tolerances in the components of the instruments) and the noises (contributed by the receiver thermal noise, losses in waveguides and waveguide components, sky noise, interference entering the earth station receiving antenna, interference entering the satellite

* E-mail address: *hossainkm_1976@yahoo.co.in*

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receiving antenna, thermal noise generated in the satellite and inter-modulation noise throughout the system). Here it has been assumed that the power of the aggregate noise to be almost constant for all the frequencies (i.e. white noise).Smoothening and filtration has been done by Finite Variance Scaling Method (FVSM) and Discrete Wavelet Transform based filtering respectively. [5]

The data, after filtration, are up sampled by padding zeroes at the missing data which is then operated by Fast Fourier Transform to get the coefficients in the frequency domain. The coefficients are squared to get the power at different frequencies nay at different periods. The peaks of this curve are then detected by the derivative and integral method algorithms. The scores of the peaks are finally checked.

2. Theory

2.1 Power Spectrum Analysis In Search Of Periodicities Of Solar Irradiance Variation

We carry out the power spectrum analysis of the denoised signal using Fast Fourier transform (FFT). The FFT of the time series signal x[n] is given by X (f_n) where X (f_k) are the coefficients of the frequency spectrum of x[n]. X (f_k) is related to x[n] by the equation

$$X(f_k) = \sum_{n=0}^{N-1} x[n] e^{-j2\pi f_k n\tau} \quad (1)$$

where, k=0,1,2,……….N-1 and τ is the sampling interval.

In our case x[n] is the time series data of the denoised solar irradiance with zero padding at the missing data. X (f_n) when plotted against the frequencies gives the frequency spectrum of the data.

The square of the absolute magnitudes of the coefficients gives the power of the signal at the different frequencies. The plot of the power as a function of frequencies gives the power spectrum of the signal. The power spectrum has some confident peaks. The frequencies corresponding to these peaks can be taken as the strong frequencies within the time series signal. The inverse of the frequencies gives the periods within the signal. Plotting the power as the function of the periods gives the periodogram.

2.2 Peak Detection Algorithm For The Search Of Prominent Peaks

Four different algorithms [5] have been used to detect the peaks of the periodogram.The algorithms are derivative based and integral based. If t_n be the discrete time then x[n] is represented by $x(t_n)$. $x(t_n)$ represents the power at the instant t_n.

2.2.1 Derivative Methods

Three algorithms are being used which are based on derivatives methods.The methods are as follows:

2.2.1.1 Method 1

Step 1: :Discrete Derivative

$$\frac{x(t_{n+1}) - x(t_n)}{t_{n+1} - t_n} = \Delta_1 x(t_n)$$

Step 2:Score

$$\max(\Delta_1 x(t_n)) - \min(\Delta_1 x(t_n)) = S_0$$

Step3: Data Set Stratification

The vector of S_0 is sorted as per their magnitude.

2.2.1.2 Method 2

Step1: Discrete Derivative

$$\frac{x(t_{n+2}) - x(t_n)}{t_{n+2} - t_n} = \Delta_2 x(t_n)$$

Step 2:Score

$$\max(\Delta_2 x(t_n)) - \min(\Delta_2 x(t_n)) = S_0$$

Step 3: Data Set Stratification

The vector of S_0 is sorted as per their magnitude.

2.2.1.3 Method 3

Step 1: :Discrete Derivative

$$\frac{x(t_{n+1}) - x(t_n)}{t_{n+1} - t_n} = \Delta_1 x(t_n)$$

Step 2:Score

$$\left[\left|\max \Delta_1 x(t_n)\right| - \left|\min \Delta_1 x(t_n)\right| \right] - \left[\max \Delta_1 x(t_n) - \min \Delta_1 x(t_n) \right] = S_0$$

Step3: : Data Set Stratification

The vector of S_0 is sorted as per their magnitude.

2.2.2 Method 4 (Integral Method)

Step1:Integral

$$\sum_{t_n} |x(t_n)| = A_1$$

Step 2:Discrete Derivative

$$\frac{x(t_{n+1}) - x(t_n)}{t_{n+1} - t_n} = \Delta_1 x(t_n)$$

Step 3: Maximum Localisation

$$\tau = \arg\max_{t_n}(\Delta x(t_n))$$

Step 4:Local Integral

$$\sum_{t_n=\tau-u}^{\tau+u} |x(t_n)| = A_2$$
$$where\ u = 1,2$$

Step 5: Score

$$\frac{A_2}{A_1} = S_0$$. A vector of S_0 is obtained.

Step 6: Data Set Stratification

The vector of S_0 is sorted as per their magnitude.

3. Results

Fig.1 represents the original signal of the daily Solar Irradiance from October, 1984 to October, 2003 obtained by ERBS.

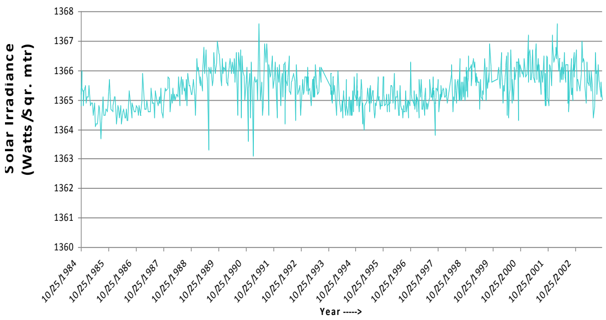

Fig. 1. Daily TSI data from October 1984 to October 2003

Fig.2 shows the signal after simple exponential smoothing and denoising. Discrete Wavelet Transform (DWT) with soft thresholding has been used for denoising. [4]

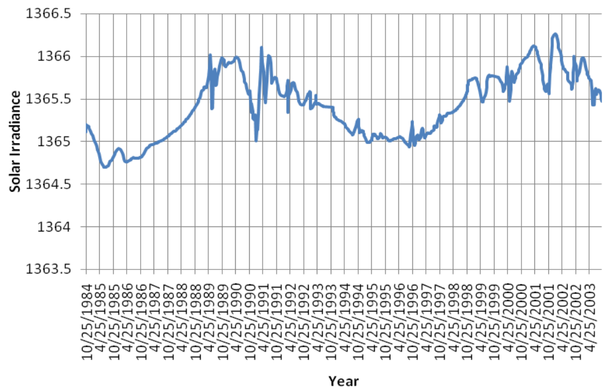

Fig. 2. Signal obtained after DWT Threshold Denoising

Fig.3 shows the frequency spectrum of the data obtained after FFT.

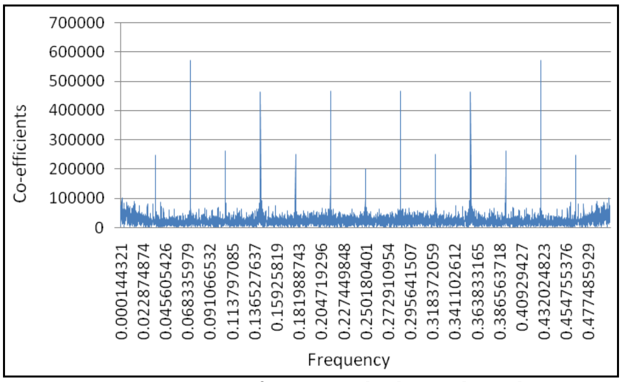

Fig. 3. Frequency Spectrum after FFT on the denoised signal

The power spectrum obtained is shown in fig.4. From the fig.4 we see the power spectrum has some confident peaks.

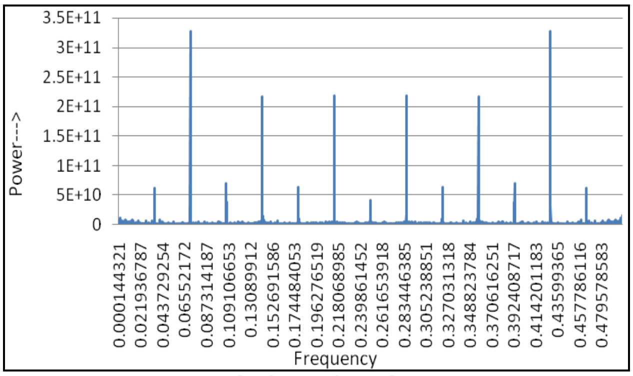

Fig.4. Power Spectrum on the denoised signal

The periodogram is shown in fig.5. In this plot the powers at higher frequencies are neglected as they may be noise powers.

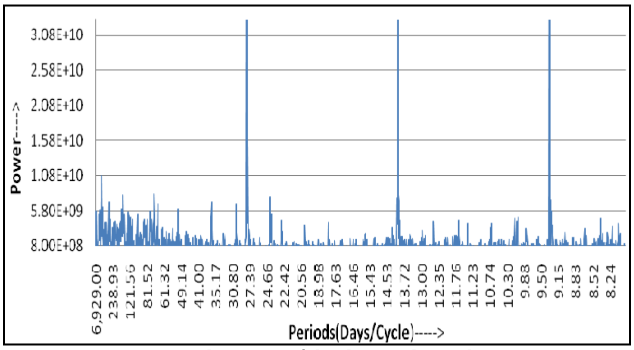

Fig. 5. Power VS Periods curves of the denoised signal

The peaks has been detected by using the derivative and integral algoritms as discussed earlier. The scores of the periods corresponding to these peaks are being calculated. The periods along with their scores are shown in table 1 for each methods of peak detection algorithms.

Table 1. Scores obtained for each periods using peak detection algorithm

Method 1		Method 2		Method 3		Method 4	
Periods	**Scores**	**Periods**	**Scores**	**Periods**	**Scores**	**Periods**	**Scores**
9.344572	1.25E+11	9.350877	3.35E+10	9.338275	1.88E+11	9.075311	2.08E-01
14.01213	6.18E+11	14.02632	2.15E+11	13.99798	9.38E+11	13.5332	3.60E-01
28.10953	1.15E+11	28.16667	3.04E+10	28.05263	1.73E+11	27.49603	1.13E-01
30.25764	7.71E+09	30.25764	4.14E+09	36.3727	1.16E+10	35.99481	1.08E-02
68.26601	1.07E+10	68.60396	3.89E+09	51.13653	1.83E+10	51.51673	1.14E-02
124.8468	9.18E+09	153.9778	3.88E+09	150.6304	1.73E+10	101.1533	4.15E-03
729.3684	1.37E+10	729.3684	1.06E+10	659.9048	2.45E+10	659.9048	3.98E-03
4619.333	1.09E+10	1259.818	3.13E+09	3464.5	1.62E+10	4619.333	2.63E-03

Following figures (Figures 6-9) depict the profiles obtained by Methods1-4 respectively.

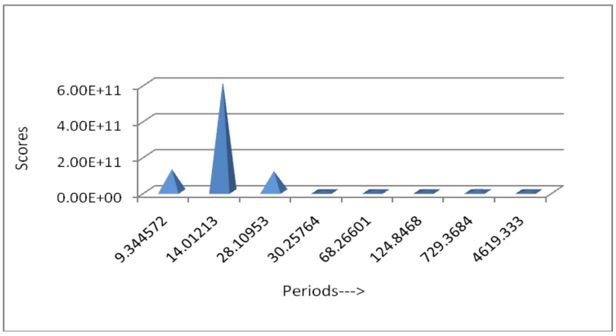

Fig.6. Scores of periods using Method 1

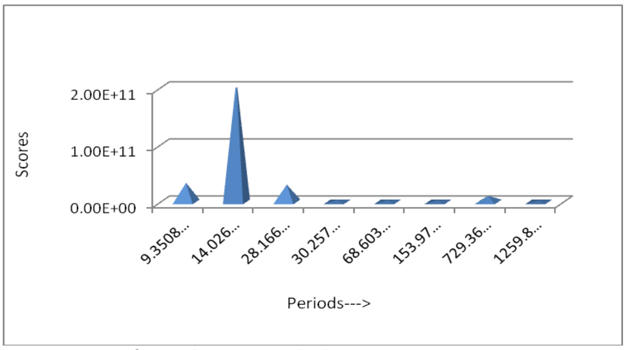

Fig.7. Scores of periods using Method 2

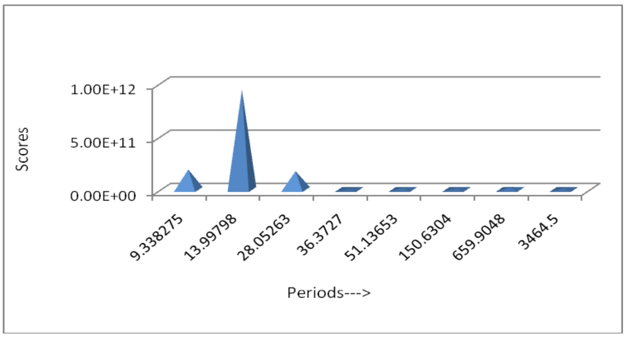

Fig.8. Scores of periods using Method 3

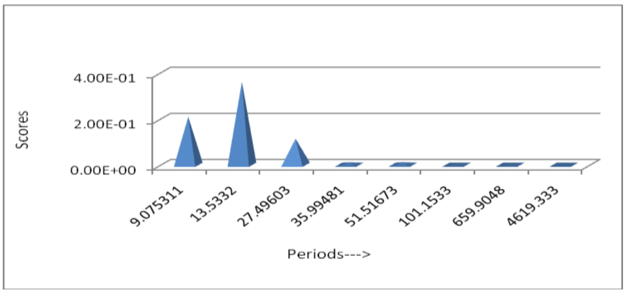

Fig.9. Scores of periods using Method 4

From the fig 6,7,8 and 9 it is evident that the periods in the range of 9.08 to 9.35 days are very strong. Other strong peaks are around 13.53-14.03, 27.50-28.17, 30.26, 35.99-36.37, 51.14-51.52, 68.27-68.60, 101.15, 124.85, 150.63-153.98, 659.90, 729.37, 1259.82, 3464.50 and 4619.33 days. Some weak periods have also being noticed around 46.19, 72.55, 82.49, 137.21-139.98, 395.94, 407.59 and 1979.71 days.

4. Discussion

The variation of solar irradiance data may provide an indication for a secular change that might be related to subtle change in the solar radius [6, 7]. Short term changes of solar irradiance data during solar activity cycles are expected to be due to the luminosity changes connected with the temperature fluctuation of the solar surface and may also be due to the redistribution of the solar radiation by sunspot and active region population. We compare our results with the corresponding published periodicities of other solar activities in table 2.

Table 2. Comparative study of the obtained periods with other solar activity periods

Serial No.	Solar Activities	Periods	Obtained similar periods in the present work
1	Solar X-ray Flares and Coronal Mass ejections during Solar Cycle 23 [8]	14 days	13.53-14.03 days
2	Solar Filament Activity [9]	367, 795, 1141 and 1557 days	395.94, 729.37 and 1259.82 days
3	Solar electron flare occurrence [10]	152 days for cycle 21, 330 and 604 days for cycle 22 and 152 days and 176 days for the current cycle 23	150.63-153.98 and 395.94 days
4	Solar Flare Rate [11]	51, 78, 102, 128 and 154 days	51.14-51.52, 82.49, 101.15, 124.85 and 150.63-153.98 days
5	Solar Proton events [12]	154 days	150.63-153.98 days
6	Solar Magnetic Cloud [13]	7 and 32 days	9.08 -9.35 and 30.26 days
7	Mean solar magnetic field [14]	14 days	13.53-14.03 days
8	Solar Chromosphere during the last three solar cycles [15]	13.5 days	13.53-14.03 days
9	The near-Earth solar wind during the last three solar cycles [15]	13.5 days	13.53-14.03 days
10	Interplanetary magnetic field during the last three solar cycles [15]	13.5 days	13.53-14.03 days
11	Geomagnetic activity during the last three solar cycles [15]	13.5 days	13.53-14.03 days
12	Solar Neutrino Flux [16]	For 5 day long samples 7.5, 699.9, 1012.5 and 1282.5 days For 10 day long sample 15, 30, 845, 1575 days For 45 day long samples 495 and 855 days	9.08 -9.35, 13.53-14.03, 30.26, 729.37 and 1259.82 days
13	Solar Neutrino Flux [17]	13.75 days(strongest period) 38.82 days(second strongest period)	13.53-14.03 and 35.99-36.37 days
14	Total area of coronal holes enclosed within a latitude band of 10–50° S [18]	592 days	659.90 days
15	Polar Coronal holes area [19]	66 days	68.27-68.60
16	Solar rotation at its equator [20]	25 days	27.50-28.17
17	Solar rotation at its pole [21]	36 days	35.99-36.37 days
18	Solar total and UV irradiances, 10.7 cm radio flux, Ca-K plages index, and sunspot blocking function [22]	13.5, 51, 150-157 and 240-330 days	13.53-14.03, 51.14-51.52, 150.63-153.98 and 395.94 days
19	Sunspot numbers & Sunspot areas [23]	Between 23.1 and 36.4 days	27.50-28.17, 30.26 and 35.99-36.37 days
20	Solar rotation during cycle22 [24]	27–41 days	27.50-28.17, 30.26 and 35.99-36.37 days
21	Solar rotation during cycle23 [24]	24–45 days	27.50-28.17, 30.26, 35.99-36.37 and 46.19 days
23	Solar flare occurrence Cycle 19 [26]	51 days	51.14-51.52
24	Solar flare occurrence Cycle 20 [26]	84 and 129 days	82.49 and 124.85 days
25	Solar flare occurrence Cycle 21 [26]	153 day	150.63-153.98 days
26	Solar flare occurrence Cycle 23 [26]	33.5 and 129 days	35.99-36.37 and 124.85 days

It is pretty much understandable from the above table and from our results that the periodicities of the Total Solar Irradiance variation have significant resemblance with the periodicities for other different solar activities. So it may be interpreted that as a whole solar irradiance has close association with other solar activities.

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