

# PERIODICITY IN VARIOUS KINDS OF SOLAR ACTIVITY

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## ABSTRACT

Sun exhibits periodicity, both short term and long term, in different kinds of solar activity. A 14-day periodicity in the mean solar magnetic field has been confirmed. The periodicity for both magnetic and non-magnetic component of total solar irradiance is found to occur around 70-days. The periodicity in solar flare indices for both magnetic and non-magnetic (Basal) component varies harmonically with time, exhibiting 5.5 year cycle of variation. A constant periodicity of 35-days is observed in the entire radio band (0.245-15.4 GHz) of the basal component of solar radio emission during the period of maximum solar activity, whereas, the periodicity fluctuates harmonically with frequency during the minimum period. A periodicity of 74-days for proton fluences indicates the intimate relationship of proton emission with solar activity. The first harmonic of the periodic values occurs around 11-14 days and the second harmonic is found to be in the range 22-27 days in the electron fluences.

## INTRODUCTION

Sun shows periodicity, both short term and long term, in different kinds of solar phenomena. The 11 year cycle observed in different kinds of solar activity, 22 year cycle in the magnetic polarity reversal and 27 day periodicity in the slowly varying component of solar radio emission are quite well known to us. Other values of periodicity in different kinds of solar activity were reported by various authors from time to time [1-9]. The knowledge about these periodic values helps us to know the physical state of the sun, whether it is in quiet, or in disturbed phase at a particular period. During quiet or non-active period the sun emits less energy, whereas, at the time of disturbed or active phase it emits higher. So if the periodicity be known exactly, it can help us to predict, in advance, the hazardous effects on the earth and bio-sphere caused due to the solar energetic emissions. Moreover, the study on the periodic behavior of sun helps us in gaining an insight into the various mechanisms involved in the different processes occurring inside the sun. Whether a particular process is chaotic or harmonic in nature, can also be judged from these studies. In the following analyses different solar data were collected from Solar Geophysical Data bulletins published by U. S. Department of Commerce.

## METHOD OF ANALYSIS

To examine the periodicity of different kinds of solar events the Fourier transformation was used. The Fourier coefficients derived from the respective time series by adopting the following principle and the most prominent peaks are found out.

We can express a signal  $g(t)$  by a trigonometric Fourier series over any interval of duration  $T_o$  as :

$$g(t) = a_o + \sum a_n \cos(n\omega_o t) + \sum b_n \sin(n\omega_o t)$$

where  $n = 1$  to  $\infty$  and  $\omega_o = 2\pi/T_o$

$a_o$ ,  $a_n$  and  $b_n$  are known as the Fourier coefficients .

We can determine these coefficients as

$$\begin{aligned} a_o &= 1/T_o \int g(t) dt && \text{for } n = 0 \\ a_n &= 2/T_o \int g(t) \cos(n\omega_o t) dt && \text{for } n = 1, 2, 3, \dots \\ \text{and } b_n &= 2/T_o \int g(t) \sin(n\omega_o t) dt && \text{for } n = 1, 2, 3, \dots \end{aligned}$$

Now we can have a single term of the same frequency using the trigonometric identity

$$a_n \cos(n\omega_o t) + b_n \sin(n\omega_o t) = c_n \cos(n\omega_o t + \theta_n)$$

where  $c_n = (a_n^2 + b_n^2)^{0.5}$  and  $\theta_n = \tan^{-1}(b_n/a_n)$

the amplitude  $c_n$  is computed from  $a_n$  and  $b_n$  using the above equations.

The significance of each of the peaks has been studied quantitatively and it has been observed that each of the peaks rises far above the three sigma level. The peak value which corresponds to the minimum value of confidence limit was chosen for each of the years.

The confidence interval or limit provides the lower and upper limits to which the population parameter has a high probability of being included. The population parameter standard deviation ' $\sigma$ ' can be calculated from the following formula :

$$\sigma = \left\{ \frac{\sum T^2}{(N-1)} - \frac{(\sum T)^2}{N(N-1)} \right\}^{0.5}$$

The standard error for sampling distribution is estimated as

$$SE_m = \sigma / (N-1)^{0.5}$$

The confidence limit for the 95% confidence can be computed as

$$C.L. = T_{ave} \pm 1.96(SE_m)$$

where  $T_{ave}$  is the mean value of the time periods of the sample data points.

## RESULTS

The periodicity of the basal component of solar radio emission in the frequency band 0.245 – 15.4 GHz was studied [10] which was restricted to the solar maximum and minimum periods only, when the corona becomes both symmetrical as well as asymmetrical in shape. In order to determine how far the sunspot activity affects the radio flux observed at various frequencies, the correlation coefficients between the daily values of sunspot number and the radio flux have been determined. It appears that the radio flux is highly correlated with the sunspot number at the observing frequency close to 2.7 GHz and this holds good for both sunspot maximum and minimum periods. A regression equation connecting the radio flux and the sunspot number has been established after plotting the scatter diagram of the two variables. The generalized equation can be written as

$$\text{Radio flux} = I + a \cdot N$$

where ' $I$ ' is the basic component of radio flux, ' $a$ ' is an arbitrary constant and ' $N$ ' is the sunspot number. The values of these constants evaluated from the analysis of the data for the sunspot maxima as well as the minima under consideration.

The value of the constant ' $I$ ' gives the radio emission flux when the sunspot number is taken to be zero; this is nothing but the basic component of solar radio emission. The sunspot independent component of radio emission is obtained when the constant ' $a$ ' is multiplied by the sunspot number of a particular day and then the product is subtracted from the observed value of the flux. When the steady part is eliminated from this sunspot independent component, the basal component is obtained. This technique is used for all the frequencies individually and four time series are formed for the years 1975, 1980, 1986 and 1991. Next an attempt has been made [11] to examine the periodicity in the basal component or non-magnetic component which has been found out after subtracting the effect due to the sunspot activity, as well as, the effect of mean solar magnetic field on the total intensity of radio emission.

The radio emission intensity, can be represented by the following relation :

$$\text{Radio Flux} = I_0 + a_0 N + b_0 M$$

where ' $I_0$ ' is the non-magnetic component of solar radio emission, ' $N$ ' is the sunspot number and ' $M$ ' is the mean solar magnetic field on the day of observation. As a consequence, ' $a_0$ ' represents the contribution to the total emission per unit sunspot number and ' $b_0$ ' that resulting from unit mean solar magnetic field. From this ' $I_0$ ' value the steady part has been subtracted in order to obtain the variable part, and this procedure has been repeated to generate the time series used for power spectral analysis.

The correlation coefficients of daily values of the observed radio flux with the respective sunspot number as well as with that of the mean solar magnetic field have been found out. It has been observed that the correlation with sunspot number increase with the increase of frequency up to 2695 MHz after which it declines with the further increase of frequency of observation. This is to be true for both solar maximum (1980, 1991) and minimum (1975, 1986, 1996) periods. But the correlation of radio flux with the mean magnetic field of sun is very poor, (less than 27 per cent), in all the frequencies for all periods under study. From the power spectra drawn for the years 1975, 1980, 1986, 1991 and 1996 at different frequencies, the spectral peaks around which the Fourier coefficients attain their maxima were determined and the periodicity values for the each year at each frequency were found out. It appears that the periodicity of 35 days remains constant throughout the entire frequency band 0.245 – 15.4 GHz during the periods of solar maxima (1980 and 1991) and the periodicity values fluctuate with ' $\log f$ ' almost in a sinusoidal way in all the cases embracing the years of solar minima (1975, 1986 and 1996).

The variation of periodicity with observing frequency can be represented by the following relations:

$$T = 52.6 + 23.5 \sin X \quad \text{for 1975}$$

$$= 54.8 + 28.8 \sin X \quad \text{for 1986}$$

$$= 57.7 + 30.6 \sin X \quad \text{for 1996}$$

where,  $X = 2\pi (\log f - \log f_o) / (\log f_1 - \log f_o)$ ,

here  $f_o$  is the frequency corresponding to zero phase angle,  $f_1$  that for  $2\pi$  phase angle, and  $f$  any arbitrary frequency in MHz. From these equations the average value of the period can be calculated as 55 day.

In order to find the periodicity in the mean solar magnetic field observed at Stanford observatory [12] using Fourier transform and autocorrelation techniques, eight time series have been made, which include the years of maxima 1980 and 1991, of minima 1986 and 1996 and also the years 1990-1991 and 1992-1993, respectively after the solar maximum in 1991, as well as 1985-1986 and 1988-1989, respectively, just before and after the solar minima in 1986. Moreover, the periodic values which correspond to the synodic rotational modulation of sun and its simple multiples have been discarded. The average periodic values have been estimated as 26.7 days and 14.02 days. In order to confirm the periodicity, in the next phase of work, the autocorrelation coefficients have been determined from each of the time series under consideration. By taking the time intervals between the two successive peaks in a sequential manner, the periodicity has been evaluated in each case. The mean values of these periods are found to be 14.00 days.

The periodicity in the solar flare indices has been investigated [13] by considering the data of the whole 22<sup>nd</sup> solar cycle (from 1986 to 1996) which would help to explore the solar cycle dependence of periodicity in flare indices. This will also result in an estimate of the average value of the periodicity in flare indices from its cyclic variation. The nature of variation gives rise to an approximate 5.5 year cycle in the periodicity of flare indices, from which it can be concluded that the periodicity is solar cycle dependent. The average period may be taken as 37 days which comes out from this cyclic variation. The plots of the Fourier coefficients against time period show several maxima from which the most prominent peaks have been evaluated. We have also applied the autocorrelation technique to the same time series in order to confirm the periodicity obtained from the Fourier transformation. In order to justify the validity of the peaks found from the Fourier analysis, the confidence limits were examined. All these confidence limits of the time periods for the different peaks correspond to the percentage confidence, better known as confidence level, above 95%.

Power spectrum analysis of the total solar irradiance was done for the period of 1981-1991. Different time series were taken for the different phases of the solar cycle and were separately treated for evaluating the periodicity. This is done for both magnetic and non-magnetic components of total solar irradiance. In both the cases, the peaks are examined to occur around 70 days.

By applying the method as stated earlier the periodicity in proton fluences was found to be 74 days for the three ranges of energy values 1 Mev, 10 Mev and 100 Mev. For the electron fluences the primary peaks occur around 24, 27 and 22 days and secondary peaks around 14, 12 and 14 days in the rising, peak, and falling phases of the 22<sup>nd</sup> solar cycle.

## CONCLUSION

In the foregoing analyses we have thrown some light on the periodic behavior of sun. It is observed that sun exhibits periodicity, both short term and long term, in different kinds of solar activity, such as, sunspots, general magnetic field, solar irradiance, flares, radio emission and high energy particle emission.

The periodicity in the basal component or non-magnetic component of solar radio emission is around 35 days in all the frequencies of observations during the periods of solar maxima and becomes equal to an average value of 55 days during the periods of solar minima, although this value varies almost sinusoidally with frequency keeping this value as an average. During the periods of solar minima the periodicity attains maximum values around 8800 MHz and 410 MHz and minimum value around 2695 MHz, this minimum value (35 days) being equal to that of the solar cycle maxima. During the period of solar cycle maxima, the non-magnetic component of radio emission may be assumed to be thermal in nature. During the period of solar cycle maxima, the corona becomes more or less symmetrical and spherical in shape and hence, the radio emitting layers are close to the center and also arranged in an orderly manner. But during the solar cycle minima, the corona becomes asymmetrical in shape. So the radio sources are situated far away from the center and are also randomly distributed. As the periodicity is directly proportional to the cube of the radius of the position of the radio emitting zone as reported by Chatterjee and Das [14] it appears that the period should become greater during the time of solar cycle minima, when the radio sources are far from the center of the sun. This statement tallies with our analyses. Again, during the solar minima, almost a sinusoidal variation with  $\log f$  is observed from the same analyses. The asymmetry in the shape of the corona is found to occur in a respective manner as the period vs  $\log f$  curves are examined to be similar in nature.

The periodicity of 14 days in the mean solar magnetic field is confirmed as it is found to occur in different phases of 21<sup>st</sup> and 22<sup>nd</sup> solar cycle. The other periodicity of 26.7 days is due to the rotational modulation of the sun. The peak around the time period of 9 days might be due to the higher harmonics of the synodic rotational modulation of the sun. It can be noted that Bogart [15] reported the existence of the same periodicities, as stated above, after analyzing the daily Wolf sunspot numbers over a period of 128 years. As the sunspot numbers show the same periodicities as it has

been found for the mean solar magnetic field and the autocorrelation is very similar, it can be concluded that the mean magnetic field of the sun is mostly dominated by the effect coming from the active regions, due to which a 14 day periodicity is observed.

It appears that the proton flux bears a linear relationship with the regional flare index per day. So if the energy output of a flare increases, the associated protons become more energetic. The relationship between the flux of proton events and the estimated energy output of H $\alpha$ -flares indicated that the acceleration of very high energy protons might be linked with the shock acceleration which was proposed as a 'second stage' acceleration process in a solar flare [16]. The 74 day periodicity of the proton fluences that has been found to hold good irrespective of their energy values clearly indicates that the periodicity is connected with the characteristics of the source region. It has been recently reported [17] that the power spectral analysis of the time series of solar flare index data reveals a periodicity of 73 days, which is in operation from November 1988 to December 1991. The same value of periodicity for proton fluences and solar activity makes us to conclude that the proton emission is so much intimately connected with the solar activity that the periodicity of one is reflected in the other.

The periodicity found out for the electron fluences is not guided by the sunspot activity as the correlation between the sunspot number and the electron fluences has been examined to be very low. The average synodic rotational rate of the corona, as derived from the green – line coronal index which seems to be the best indicator of the coronal effects of magnetic activity erupting from the photosphere, is about 27.2 days. As the most electrons are coming out of the corona, the periodicity in the electron fluences might be governed by the coronal features which is indicated by the coronal indices, having the periodicity similar to that of the electron fluences.

Now the new periods which we have investigated are displayed in the following Table 1.

**Table 1. Short term periods investigated in different kinds of Solar activity**

Solar events	Values of periodicity in days
Radio emission in microwave band (during sunspot maxima)	35
Mean solar magnetic field	14
Flare indices (Magnetic and Basal component)	37
Solar irradiance (Basal component)	70
Proton fluences (1,10 and 100 Mev)	74
Electron fluences	11-14

It appears from the above table that mean solar magnetic field and electron fluences have short term periodic values around 11-14 days, flare indices and radio emission in the microwave band around 35-37 days, and basal component of solar irradiance and proton fluences around 70-74 days. Again, 70-74 days periods are harmonics of 35-37 days. Moreover, 11 –14 days periods may be looked upon as the harmonics of the synodic rotational modulation of sun. So the question arises, does the sun possess a short-term fundamental period around 35-37 days, other than the standard period of 27 days.

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