Periodic behavior of solar electron flares during descending phase of cycle 23

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Abstract: We report for the first time the short and intermediate-term periodicities in solar electron flares in two different energy bands during the recent solar minimum of cycle 23 using 5.7-year data (1 June 2003 to 31 December 2008) from the Geostationary Operational Environmental Satellites (GOES). The wavelet power spectrum analysis shows a number of quasi-periodic oscillations in both data sets. In the high frequency range, prominent periods of 10-16 days, 22-35 days including 27-day oscillation are detected. Other quasi-periods such as 40-60 days, 100-110 days, 120-130 days, 140-160 days, 180-190 days, around 250 days, ~400 days and ~1.3 years are found in different phases of descending epoch of cycle 23. Possible explanations of the observed periodicities are given in terms of solar r-mode oscillations.

Keywords: Sun: activities, periodicity, and energetic particle events.

1 Introduction

The Sun’s activity is key to understanding the geophysical processes (e.g., global change, climate change, geomagnetic disturbance, space weather, atmospheric circulation etc.). The periodic behavior of the Sun is well known in terms of 11-year sunspot cycle (Schwabe cycle) and 27-day rotational modulations. Investigation of periodic behaviour in different time-scales of the Sun’s activity started with a landmark discovery of ~154 days quasi-period in solar γ-ray flare occurrence [1] during maximum phase of cycle 21. Since then, several short and intermediate term periodicities have been detected [2], using different solar parameters of different solar cycles. Observations have also revealed that most of the energetic solar flares produce an enormous amount of interplanetary charged particles.

Energetic charged particles emitted from the Sun have significant effects in the near-earth space environment, in the atmosphere and in the space-borne spacecrafts [3]. Energetic electrons in the outer Van Allen radiation belts can penetrate spacecraft walls, creating an excess potential difference. This can result in degradation of spacecraft memory devices [4] and can cause severe damage to various sub-systems of the satellite. Medium energy electron flares can cause satellite surface charging. The insulated surfaces may drastically change by several kilovolts potential (negative relative to ambient plasma) which can change physical, chemical and optical properties of the satellite systems [5], and interrupt normal spacecraft operations. The magnetic storm activity index (Dst) is also associated with the occurrence of electron flares [6]. Therefore, prediction of occurrence rate of electron flares is very important for geostationary satellites and space weather applications.

In the present paper, we have studied the periodicity and their temporal evolution of both medium (E > 0.6 MeV) and relativistic energy (E > 2 MeV) electron flares during descending phase, including minimum of cycle 23.

2 Data and Analysis Methods:

The daily values of solar electron flares of two different energy values (E > 0.6 MeV and E > 2 MeV) are recorded by Geostationary Operational Environmental Satellites (GOES) and have been taken from Space Weather Prediction Centre (www.swpc.noaa.gov) and also from National Geographical Data Centre (NGDC). However, there exists a long data gap in both data sets from 8 April 2003 to 13 May 2003. Therefore, we have considered our analysis from 1 June 2003 to 31 December 2008. The data sets are the residuals, after the background is subtracted, taken in a regular manner and covers the entire descending phase, including minimum of cycle 23.
We have studied periodic behavior of electron flux data using Morlet wavelet function [7]:

\[
\Psi (\eta) = \pi^{-1/4} e^{i w_0 \eta} e^{-\eta^2/2}
\]

which is a sine wave with an amplitude windowed in time by a Gaussian function. Here \( w_0 \) is non-dimensional frequency which has been chosen as \( w_0 = 6 \), considering a red noise background spectrum. In addition, the cone of influence (the regions of wavelet diagrams where power reductions become important) is shown by bold-dashed line. The thin-black closed contours demonstrate the periods above 95% confidence level.

3 Discussion and Conclusions

Extensive analyses have been carried out to detect the intermediate term periodicities in the range of 8–500 days for the daily data of solar electron flares in two different energy bands during descending phase of cycle 23. Several mid–term periodicities have been detected in the wavelet analysis. The well known Rieger period (140 - 160 days) and ~ 1.3 years oscillations are also detected during descending phase. Periodicity in the 13-14 day range comes mainly from episodic of solar activity with two peaks per rotation produced by the solar rotational modulation from two groups of active regions approximately 1800 apart in solar longitude. As a possible mechanism of the periodicities, Sturrock (8-9) and Knaack et al. [10] have suggested that the Rieger and similar Rieger–type periodicities are related to physical properties of Rossby type waves or r–modes [11].

The r–modes are retrograde waves which can be classified by spherical harmonic indices (l, m, n) where l, m and n respectively are degree, azimuthal and radial order.

In case of Rossby waves, for \( n = 1 \) (2) with even \( m = 2, 4, 6, 8, 10, 12, 14, 20 \) and 32 the estimated periods are: 31.57 (35.89), 53.4 (55.6), 77.4 (78.9), 101.9 (103.0), 126.7 (127.6), 151.6 (152.3), 176.6 (177.2), 251.6 (252.0), and 402 (402.1) days respectively.

For odd values of \( m = 1, 3, 5, 7, 9, 11, 13, 15, 19, 33 \) and 39 with \( n = 1 \) (2), the corresponding periods \( P_r \) estimated are:

\[
25.50 (34.13), 41.96 (44.84), 65.3 (67), 89.7 (90.9), 114.4 (115.3), 139.2 (139.7), 164.1 (164.3), 189.1 (189.6), 239.13 (239.58), 414.54 (414.8) \text{ and } 489.78 (490.0) \text{ days respectively. These periodicities are in good agreement with the periodicities detected in our present study of solar electron flares.}
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When the mixed waves are considered, then for even \( m = 2, 4, 6, 8, 10, 12, 14 \) and 20, the relevant periods \( P_r - p \) are 27.07, 51.2, 76, 100.9, 125.8, 150.8, 176, and 251.2 days respectively. For odd \( m = 3, 5, 9, 11, 13, 15, 19 \) and 39, the periods are 39.3, 63.5, 113.4, 138.4, 163.4, 188.5, 238.6 and 489.55 days respectively. These values are very close to some periodicities found in the present investigation. This investigation, therefore, provides a useful overview of the main quasi-periodic oscillations that have occurred in energetic particle events during the descending phase of cycle 23. More observations and theoretical investigations on the dynamics of the solar corona are required to explain the origin of these short and intermediate-term periodicities in the solar activity.

4 REFERENCES

Table 1: List of the periods and occurrence intervals detected in the present investigation from Figures 1 & 2