A Search for Systematic Periodicities in Solar Flares

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Abstract. In recent years, a number of researchers have claimed that the occurrence times of solar flares exhibit discrete intermediate periods ranging between 25 and 150 days and even longer. Subsequently, Sturrock & Bai (1992, ApJ 397, 337) proposed the existence of a sub-surface oblique rotator which, they claim, can account for many of these intermediate periods. In this poster, we present results from a detailed frequency analysis of a large data base of Hα flares between the years 1938 and 1991. From this analysis we show that, while solar flares do exhibit a number of periodicities, these periodicities are intermittent and often non-recurring. Given the sporadic nature of the observed periods, we feel that we cannot affirm the oblique rotator model, and suggest that it is premature to draw conclusions about the solar interior from a frequency analysis of solar flares.

1. Introduction

Solar flares are associated with unstable configurations of magnetic elements. A temporal distribution of solar flares on the surface of the Sun resembles a butterfly diagram (Balasubramaniam & Regan 1994) similar to a sunspot butterfly diagram – a typical 11-year cyclical variation. Since changes in the number of

1Supported by the AFOSR and Space Hazards Branch, Air Force Research Laboratory

2Operated for National Science Foundation by the Association of Universities for Research in Astronomy.

3Supported by the NSO/NOAO REU Program
sunspots on the solar surface can be understood in terms of an internal dynamo, and since the distribution of flares also resembles a butterfly diagram, can the rate of occurrence of flares be traced to this dynamo? If so, studies of flares and their occurrence times could yield valuable information on the nature of this dynamo. In recent years frequency analyses of a number of different flare time series have revealed so-called “intermediate” periods, i.e. periods between the Carrington rate and the 11 year sunspot activity cycle.

Rieger et al. (1984) used 139 flares observed by the Gamma-Ray Spectrometer on SMM between 1980 February and 1983 September to show that the flares exhibit a 154 day periodicity. This periodicity has been verified in Hard X-Ray Burst Spectrometer data, also on SMM. An analysis of 8821 Hx flares recorded from 1965 - 1984, by Ichimoto et al. (1985) revealed periods of 154.9 days and 53.1 days in Solar cycle 20, and periods of 153.1 days, 78.5 days, and 110.9 days in Solar cycle 21. Since these initial inferences, a number of researchers have found similar periodicities that are usually some multiples of about 25 days or thereabouts, using a variety of data sources (Bogart & Bai 1985; Lean & Bruecker 1989; Silverman 1990; Carbonel & Ballester 1990; Bai & Cliver 1990; Kile & Cliver 1991; Bai 1992; Ozguc & Atac 1994).

Periods of ≈ 25.5, 51, 78, 104, 129, 154 days are observed in solar flare and an assortment of other data for various intervals. These periods appear to be intermittent, often disappearing and reappearing, sometimes 1/2 period out of phase. The periods also do not operate simultaneously. Some periods are active at times, and at other times other periods are active. A period active in a small interval embedded within a larger dataset can dominant the frequency analysis of the entire dataset. A period active in one hemisphere can dominant the frequency analysis of the whole solar disk.

Bai & Sturrock (1991) note that the periods 51, 78, 104, 129, 154 are all integer multiples of 25.8. These periods could therefore be considered sub-harmonics of the 25.8 day “fundamental”. A well studied non-linear system is Duffing’s equation:

\[
\frac{d^2x}{dt^2} + k \frac{dx}{dt} + x^3 = B \cos \omega t.
\]

Depending on the values of k and B the system exhibits periodic behavior at sub-harmonics, and for other values can become chaotic. These authors suggest that the “154 day complex” of periods may be the result of a non-linear response to a “clock” within the sun. Based partially on these analyses Sturrock & Bai (1992) infer a sub-surface oblique rotator which can account for many of these intermediate periods. Bai and Sturrock (1993) derive the frequency of the rotator \( \nu_r \) and the angle of inclination to the surface rotation axis \( \Omega \), by a spatial and temporal study of flares. They obtain:

\[
\nu_r \approx 25.5 \text{ days}
\]

\[
\Omega \approx 40^\circ
\]

They also show evidence that the rotator consists of “exciters”, active bands of longitude in the frame of the rotator which are separated by roughly 180°. They propose that when these exciters pass under active regions they increase the number of flares in that region.
In this report we present a detailed frequency analysis of a large flare database, showing the distribution of strong intermediate periods between the years 1938 - 1991, and make inferences on the stability of these frequencies and consequences on the internal structure of the Sun.

2. Data Reduction

The data used in this study are from a NOAA database, and have been used by Balasubramaniam & Regan (1994). The database contains data from Solar Geophysical Data Reports. These have not been processed for repeated reports of the same flare; no group reports or group numbers are available.

Because flares are often reported many times by different observatories, the data must be cleaned so that the flare time series reflects the actual number of flares on the sun. We have done this by comparing the date, time, latitude, and central meridian distance of flares. Flares with the same date, any of the listed times (begin time, end time, max time) within 5 minutes of each other, and for which the latitudes and central meridian distances are within 3 degrees are considered observations of the same flare. In these cases the first flare is retained in the data and any other repeats are removed.

Because it is questionable whether flares with multiple brilliant points (MBP) are to be considered separate flares, a separate dataset has been compiled in which repeat observations for which the flares had multiple brilliant points are considered as separate flares, and are retained in the data.

We have thus three datasets, raw data (repeat observations included), cleaned data (repeat observations removed), and cleaned data with MBP flares retained. From these three datasets we form a number of time series.

The time series consist of flare counts per day versus Julian day referenced to 1938 January 1 (the first year for which we have data). Since it is evident from previous research that different periods can arise in each hemisphere, we have also formed a time series separately containing only flares from the northern and southern hemisphere, respectively. As the data are collected from a number of ground stations, it is not clear whether the data can be considered complete, i.e., whether missing days indicate there were no flares on the sun, or are simply considered missing data. To provide for an answer to this question we have created for each time series a version in which missing data are considered zero flares/day and a version in which missing data are simply nonexistent.

3. Analysis

The time series have been analyzed using the Scargle Periodogram defined as follows: For a time series \(X(t_i)\), where \(i = 1, 2, \ldots, N_0\),

\[
P(\omega) = \frac{1}{2} \left\{ \frac{\sum_{j=1}^{N_0} X(t_j) \cos \omega(t_j - \tau)^2}{\sum_{j=1}^{N_0} \cos^2 \omega(t_j - \tau)} + \frac{\sum_{j=0}^{N_0} X(t_j) \sin \omega(t_j - \tau)^2}{\sum_{j=1}^{N_0} \sin^2 \omega(t_j - \tau)} \right\}
\]
where \( \tau \) is obtained from

\[
\tan(2\omega \tau) = \frac{\sum_{j=1}^{N_0} \sin 2\omega t_j}{\sum_{j=1}^{N_0} \cos 2\omega t_j}
\]

When the periodogram is normalized by the total variance of the data

\((P_N(\omega) = P(\omega)/\sigma^2)\), the False Alarm Probability can be defined as follows:

\[
FAP = 1 - [1 - e^{-z}]^{N_i},
\]

where \( z \) is the normalized power and \( N_i \) is the number of independent frequencies possible in the data (Horne & Baliunas 1986).

We performed a sliding-window analysis, with a window size of 2 years and then stepped through the data in 3 month steps. At each step we calculated the normalized periodogram and filtered out frequencies below 3 millicycles/day. Normalized periodograms for the years 1977-1979 (near solar minimum) and for the years 1989-1991 (near solar maximum) are shown in Fig. 1. We calculated for each periodogram \( 1 - FAP \), which gives the probability that a period is real. We then contoured these data over years between 1938 - 1991 and frequencies between 0 and 50 millicycles/day. These time-frequency (TF) diagrams show frequencies at 1, 2, and 3 \( \sigma \) levels and the interval in which they were operative. See cut-off values at 1, 2, and 3 \( \sigma \) levels, in Fig. 1.

TF diagrams for the raw data are shown in Fig. 2, and for the cleaned data in Fig. 3. The periodograms are formed from 2 years of data (see text above on sliding-window analysis) chosen for 3-month intervals. The periods in the 154-day complex are shown by dotted lines. From Fig. 2 we see that there is a paucity of contours before 1958, representing paucity of observations before International Geophysical Year (IGY, \( \sim \) 1958). Counting flares in a day when no flares are reported as zero flares in a day can result in erroneous frequencies, particularly before the years 1958. Observations of solar flares after IGY are essentially complete, with hardly any missing days. Notice that none of the frequencies are periodic over time, they randomly appear and disappear, and have no preference for solar maxima or minima.

4. Conclusions and Discussion:

Several things are apparent from this analysis: (a) There is essentially no difference between raw, cleaned, and MBP datasets, as far as the periodicities are concerned. It appears that no essential difference is generated by cleaning the data. This being the case, we are not overly concerned about the robustness of our cleaning algorithm. (b) Prior to IGY (1957-58), the time-series with missing data, and time-series with missing data considered zero do appear somewhat different. As has previously been noted the data prior to IGY are very sparse and incomplete. This is evident in the stack plots. Since the plots do not change appreciably after those years it can be concluded that the post IGY data are reasonably complete.
Figure 1. A sample periodogram for the years 1977-1979 (near solar minimum) (top) and for the years 1989-1991 (near solar maximum) (bottom) in frequencies between 0 and 50 millicycles/day. Various periods are indicated by vertical dotted lines.
Figure 2. Frequency of occurrence of solar flares between the years 1938–1991. Contours represent normalized power-spectra at 1, 2 and 3 sigma levels. Horizontal dotted lines represent periodicities of 150, 125, 100, 75, and 25 days, respectively, as one moves from top to bottom, in each panel. Top horizontal solid line represent frequencies of one year. Bottom solid horizontal line represents a frequency of one Carrington rotation. Fig. 2(a. Top) – Raw Hα data, 3 month step. Fig. 2(b. Bottom) – Raw Hα data, 3 month step, missing data considered zero flares/day.
Figure 3. Similar to Fig. 2, but the data has been cleaned to remove multiplicity of observations. Top (a): Cleaned Hα data, 3 month step, missing flare days uncounted. Bottom (b): Cleaned Hα data, 3 month step, missing data considered zero flares/day.
Looking at the positions of eras of the 154-day complex periodicities in relation to the time of solar maximum, we see that there appears to be nothing special about solar maximum. Periodicities do not seem to either cluster around solar maximum or cluster away from solar maximum. Epochs of periodicity do not appear to especially straddle solar maximum. This contradicts the view of the oblique rotator hypothesis. According to this view two exciters on the rotator pass under active regions, enhancing the number of flares produced by the active region. From this we would expect the effect of the rotator to be strong during solar maximum when there are many active regions on the sun, but might disappear during solar minimum, because of a lack of active regions on the Sun. This is not seen in the data.

Nothing systematic can be seen in the data at any of the frequencies in question. The data appears to be essentially randomly distributed.

Based on this analysis, we cannot confirm the existence of an oblique rotator within the sun. Given the sporadic nature of the periods and given that the Carrington rate (a known rotation) does not appear in the data, we feel that it is premature to draw conclusions about the solar interior from a frequency analysis of solar flares.

Acknowledgments. This work was supported by AFOSR Task 2311G3.

References