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On the recurrence of sudden ionospheric disturbances

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Abstract. Recurrence tendency of maximum sudden ionospheric disturbances (SIDs) has been investigated using power spectrum analysis. The power spectrum obtained shows that most significant power appears at the frequencies of 0.03703, 0.05555 and 0.07407 cycle day^{-1}, indicating periods of 27.02, 18.0, and 13.5 days respectively. This shows that at least four 'active longitudes' in two pairs exist on the solar disc. Each pair is separated by 60° in longitude, and corresponding active longitudes of a pair are separated by 180° in longitude. It is also inferred that the timescale of the evolution of magnetic configuration of active complex prior to flare build-up is in the vicinity of 18.0 days.

Key words: sudden ionospheric disturbance (SID)—power spectrum—solar flares

1. Introduction

Sudden ionospheric disturbances (SIDs) result from an interaction of the solar flare radiation with the constituents of the earth's upper atmosphere. The statistical relationship between various kinds of SID events and the solar ionizing radiations have been examined by many authors. Bracewell & Straker (1949) and Ellison (1953) concluded, in the absence of relevant information on x-ray flux of solar flares, that the SIDs show a close correspondence with the H-alpha emission of solar flares: both follow generally the same trends and are similar in magnitude also. Lindsay (1964) showed from a detailed comparison of some 60 x-ray flares that the use of H-alpha emission alone can be grossly misleading.

For a detailed examination of SIDs, solar flare x-ray bursts were used by Kreplin *et al.* (1962), Mitra (1966) and Deshpande *et al.* (1972); microwave bursts were used by Dasgupta *et al.* (1973) and EUV bursts by Richard (1971). The highest percentage of occurrence of SIDs, about 90%, is found for x-rays in 10–50 keV range. The capability of an x-ray flare to produce an SID depends both on the flux and on the degree of spectral hardening. Considering both these factors, Deshpande *et al.* (1972) found that about 73% of x-ray flares that produce SIDs have flux levels and spectral hardening above the threshold values of 1×10^{-3} erg cm^{-2} s^{-1} and 1.5×10^{-2} respectively.

Richard (1971) examined 78 EUV burst events with EUV flux changes and concluded that if the change in EUV flux, (ΔEUV) $> 3\%$ at $\lambda = 304$ Å or 630 Å, there is an 85% probability of the occurrence of sudden frequency deviation (SFD) whereas if Δ(EUV) $> 4\%$, the SFD occurrence probability is 100%.

In this paper, an attempt has been made to investigate the recurrence tendency of SIDs and, in turn, of the energetic solar flares through power spectrum analysis of SID time series. Such analysis may throw some light on the flare build-up mechanism and relaxation times for the flares on the solar disc.

2. Observational data

The observations of SIDs are taken from the Solar Geophysical Data. Keeping in view the strong correlation on SIDs with solar activity, the maximum solar activity period from 1978 January to 1982 september was selected for this study. For each day the total number of SID events was obtained and a power spectrum analysis of the time series without any data windows carried out (*cf.* Blackman & Tukey 1958). The resulting power spectrum for a lag of 1/20 of the total data length is shown in figure 1, which shows that significant power appears at a frequency of 0.06976 cycle day $^{-1}$ indicating a period of 14.3 days.

Another power spectrum of this data for a lag of 1/8 of the total data length is shown in figure 2. Here the significant power appears at frequencies of 0.03703, 0.05555 and 0.07407 cycle day $^{-1}$, indicating periods of 27.02, 18.0, and 13.5 days respectively. All the three peaks of figure 2 are the resolved components of the

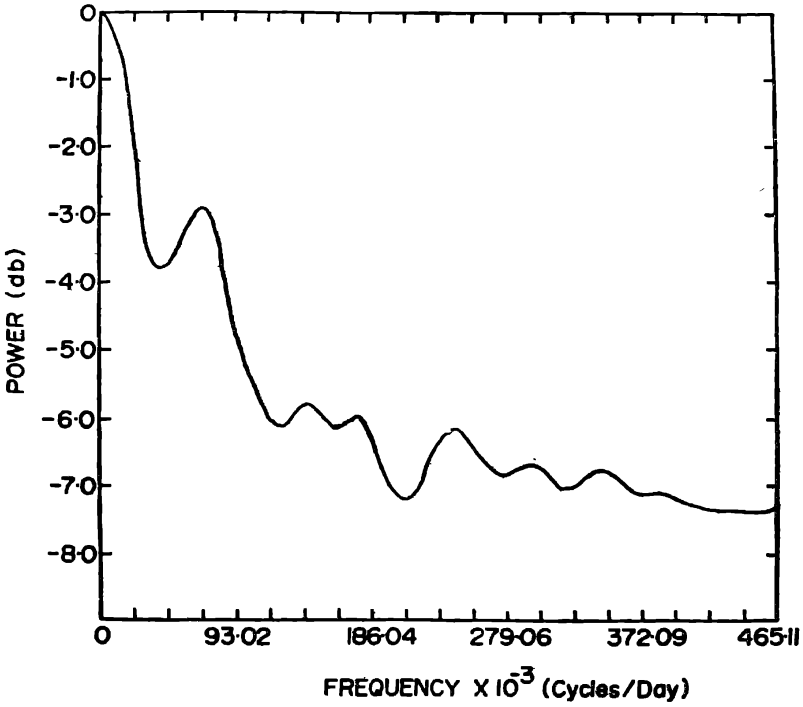

Figure 1. Power spectrum of SID occurrence. The peak at frequency of 0.0697674 cycle day^{-1} is prominent, showing the presence of an oscillatory component of period 14.3 days.

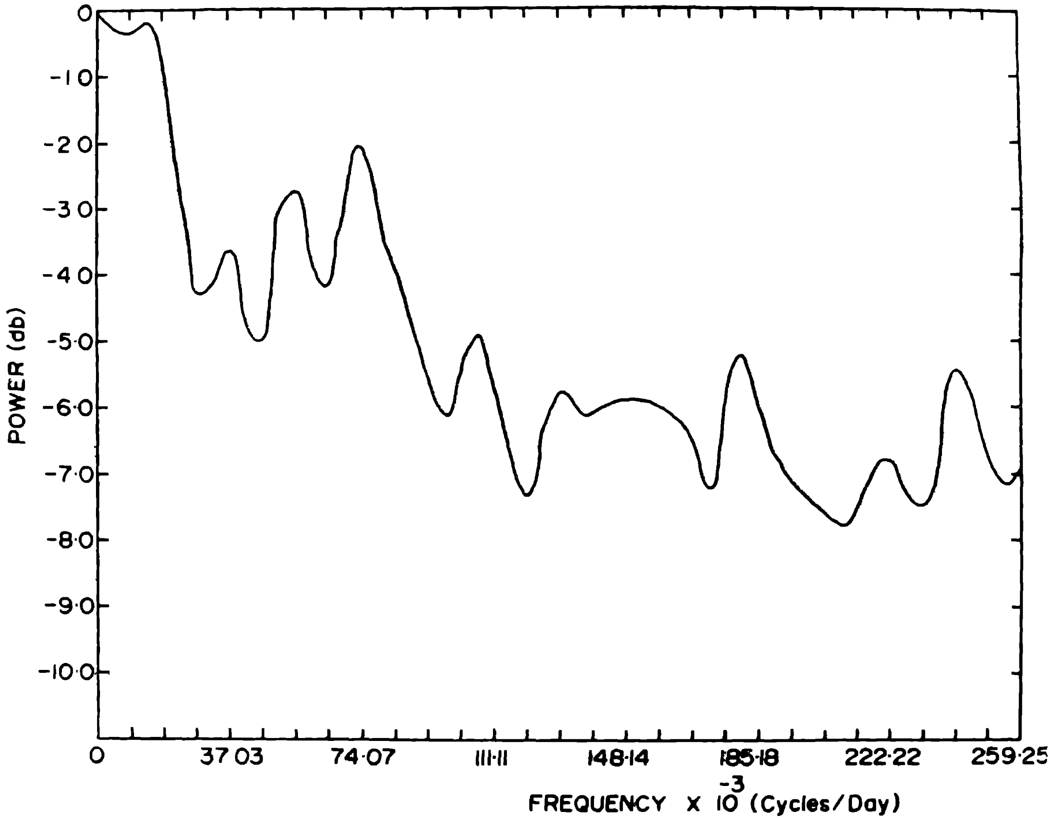

Figure 2. Power spectrum of SID occurrence. All the three peaks appeared at 0.03703, 0.05555 and 0.07407 cycle day^{-1} are the resolved components of the peak at 0.06976 cycle day^{-1} in figure 1.

peak at 14.3 days in figure 1. The remaining peaks in figures 1 and 2 carry inappreciable power and have therefore been ignored.

3. Discussion and conclusions

Our power spectrum analysis indicates that a systematic pattern exists in the occurrence of SID events. Further, the power spectrum (figure 2) reveals several expected features and some unexpected ones as well.

The power spectrum obtained (figure 2) shows broad peaks at a rotation period of 27.02 days and at its first harmonic at 13.5 days, besides the peak at 18.0 days. The peak at 27.02 days is clearly the result of an oscillatory behaviour of longitudinal pattern of solar activity that persists for a duration longer than one solar rotation. The SIDs are highly correlated with x-rays, EUV and microwave bursts. Therefore, the probability of recurrence of maximum number of strong flares producing x-rays, EUV and microwave bursts capable of causing SIDs can also be inferred from the present power spectrum analysis. Consequently, we conclude that the maximum number of strong flares, associated with x-ray bursts of energies and spectral hardening above the threshold of 1×10^{-3} erg cm^{-2} s^{-1} and 1.5×10^{-2} respectively and associated with GRF bursts of sizes about 60 and 20 flux units and with EUV bursts of flux changes greater than 4%, have a strong tendency to recur with a period lying between 13.5 and 18.0 days.

The power spectrum analysis of SIDs is an elegant way of monitoring high-energy activity on the sun. However, an interpretation must follow a careful consideration of the method of analysis. The 13.5- and 18.0-day peaks in the power spectrum may be interpreted in two ways. The first interpretation concerns the existence of long-lived spatial structures on the solar surface, whereas the second interpretation concerns the temporal evolution of active regions. The long-lived structures may be converted into timesignature by the solar rotation, while the temporal evolution is directly a time signature. Hence both would appear as peaks in the power spectrum of a time series.

The 13.5- and 18.0-day periodicities of the solar flare occurrence may be interpreted as due to the existence of a few sites of unusually strong solar activity which rotate spatially with a rotation period of 27.02 days. These few sites are the preferred longitude zones of solar activity from which the energy is released in the form of solar flares and they are systematically located on the solar surface. These energy-release sites are analogous to the active longitudes discussed in the literature. From the large-scale ordering of activity in complexes of activity (Bumba & Howard 1965) and the results concerning the distribution of activity in longitudes (Warwick 1965; Svestka 1968), several authors have pointed out the existence of active Carrington longitudes (Warwick 1965; Bumba & Howard 1965, 1969; Dodson-Prince & Hedeman 1968; Svestka 1968). The concept of active longitudes has two connotations in the literature. First there is the fundamental concept of active longitudes in a frame of reference fixed to the sun and rigidly rotating with it. Evidence of this was given long ago by Losh (1938), and also by Trotter & Billings (1962) in cycle 19. In this case the sunspots or active regions are all artificially rotated back to their positions at some given standard epoch assuming the laws of rotation and differential rotation. Thus it is only after subtraction of the differential rotation that active longitudes can be seen.

The other kind of active longitudes is due to the persistence of large active complexes over several rotations. In this case if synoptic charts were to be prepared then one would see different active complexes actually existing at different longitudes at different times. Svestka (1968) analysed some 174 proton flares in 81 different active regions over a 10-year period and concluded that active regions producing proton flares are not randomly distributed on the solar disc, but tend to occur in complexes of activity which stay on the solar surface for many months and in some cases even for several years.

A Fourier analysis of a 122-year segment of Wolf sunspot numbers carried out by Knight *et al.* (1979) has revealed an interesting feature corresponding to an apparent periodicity of 12.07 days (synodic). Further, most recently the autocorrelation coefficients of daily Wolf sunspot numbers over a period of 128 years were examined by Bogart (1982). His power spectrum showed a broad peak only at 27.5 ± 0.05 days (rotation period) and at its first harmonic 13.6 ± 0.25 days; otherwise the spectrum is extremely flat. In view of much shorter sunspot lifetimes, Bogart interpreted the 27.5-day period as an evidence for the persistence of 'active longitudes' for periods up to a year, and the 13.6-day peak in terms of a tendency towards developing simultaneous active sites separated by 180° in longitudes as suggested by Kiepenheuer (1953).

The 13.5- and 18.0-day peaks in our power spectrum indicate the existence of a few long-lived spatial structures called energy-release sites, or locations of high flare activity, or active longitudes, on the solar surface. The 13.5-day periodicity of solar flare occurrence indicates that two active complexes of high flare activity exist in a pair perhaps with a preference for separation by 180° in longitudes. The peak at 27.02 days is clearly due to the rotation of such a complex of activity that persists for longer than one solar rotation. Further, an additional peak at 18.0 days may be interpreted as being due to existence of another pair of active longitudes separated by 180° in longitudes. Each active longitude of high flare activity of this pair is separated by 60° in longitude from the corresponding active longitude, because of the 13.5-day peak. This shows that at least four active longitudes of high flare activity in two pairs exist on the solar surface; each pair is separated by 60° in longitude, and each active longitude of a corresponding pair is separated by 180° in longitude.

This interpretation of the 13.5- and 18.0-day periods in terms of spatially separated pairs of active longitudes has some very severe limitations. Both autocorrelation and power spectra are not sensitive to phases but only to periodicities. Therefore the 13.5- and 18.0-day periodicities seen in such power spectra must be interpreted bearing this fact in mind. The existence of the two 60°-separated active longitude pairs can only be checked by drawing synoptic charts and actually superposing the maps of several rotations. From these superpositions one can know more convincingly about the phase differences (or longitude differences) among more than one active complexes. It would be interesting to explore this possibility by identifying the long-lived active complexes using magnetic field synoptic charts. As long as such phase reconstruction through superposition of synoptic charts is not available, one may only infer about spatial separation of several active longitudes.

Quite independently, the 18.0-day peak in the power spectrum may be interpreted in terms of temporal evolution of active complexes. The magnetic evolution of active complexes is directly a time signature and would appear as peaks in the power spectrum of time series. Therefore the explanation of the 18.0-day period may lie in the history of magnetic evolution of large complex active longitudes. The force-free fields of opposing polarities in such regions will have the neutral line twisted by rotation of the footpoints resulting in a magnetic energy build-up in sheared fields, and this energy may be later released in the form of flare energy (*cf.* Tanaka & Nakagawa 1973). If statistically the period for such flare build-ups and the subsequent release of energy in the form of flares turns out to be in the vicinity of 18.0 days, then the occurrence of the peaks in the power spectrum can be understood.

It would be interesting to explore this possibility by using extensive data including the daily positions of sunspots, the daily H-alpha filtergrams and magnetograms in the vicinity of large active complex active regions. In this case, even the first pair is not really necessary because a single dominant and long lasting active complex with a spatial half width ~180° can yield the 27-day period, while the 13.5-day period will result from the disappearance of this complex behind the visible hemisphere for half a rotation. The interpretation of the 18.0-day period as the timescale for evolution of magnetic configuration prior to flare build-up is very attractive, since it may have its application in stars which show solar activity-like phenomena.

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