STUDIES OF SOME ASPECTS OF SOLAR PROTON EVENTS AND RELATED PHENOMENA

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ИССЛЕДОВАНИЕ НЕКОТОРЫХ АСПЕКТОВ СОЛНЕЧНЫХ ПРОТОННЫХ СОБЫТИЙ И СВЯЗАННЫХ ЯВЛЕНИЙ

Было предпринято статистическое исследование протонных событий происшедших в период 1955—1985 гг. Были получены следующие важные результаты: (I) частотное распределение появлений протонных потоков следует степенному закону, (II) скорость подъёма протонного потока изменяется непосредственно с 1.2 степенью значений потока, (II) несмотря на то, что протонные события более или менеее следуют за фазой солнечного цикла, они были максимальными в 20 солнечном цикле, пик которого был менее интенсивным, чем пики 19 и 20 циклов, (И) асимметрии И—S и E—W показывают определенные зависимости от широты и долготы соответственно.

A statistical investigation has been done of the proton events which occurred during the period from 1955 to 1985. The important results obtained are as follows: (i) the occurrence frequency distribution of proton fluxes obeys a power law, (ii) the rate of rise of proton flux varies directly with the flux valces with exponent 1·2; (iii) although the occurrences of proton events more or less follow the phase of the solar cycle, they are maximum at the 20th solar cycle peak which is less intensive than those of the 19th and 21st cycles, (iv) N—S and E—W asymmetries display definite latitude and longitude dependences, respectively.

Key words: Sun: proton events, proton fluxes

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1. Introduction

The distribution of proton events in relation to the associated active regions has proved to be of great interest in elucidating the catastrophic behaviour of these events in the solar atmosphere. Castelli and Tarnstrom (1978) found that the Carrington longitude region 150°−180° is most proton-productive, whereas the 300°−360° region is the least. They further asserted that the distribution of proton events on the solar disk shows a definite E−W asymmetry. Haurwitz (1968) made a study of the longitude distribution of proton flares, metre wave bursts and sunspots, and observed that proton flares and also the flare-associated metre wave bursts were distributed non-randomly in solar longitude in a rigidly rotating system with a period considerably shorter than the Carrington period, but no such non-randomness was observed in the distribution of sunspots associated with such flares. Švestka (1972) found that the acceleration of protons as well as electrons occurred only in groups with high levels of radio emission and complex magnetic fields with high gradients. Particle-producing regions are found to cluster into active complexes at certain preferred longitudes. The present paper deals with some of the aspects of the distribution of proton events in relation to their respective characteristics as well as with respect to the various features of the associated active regions.

2. Data Collection

The different data of proton events were obtained from the bulletins entitled "Significant Solar Proton Events, 1955−1969, 1970−1972" and "A Catalogue of Proton Events 1966−1976 having non-classical solar radio burst spectra" issued by the Air Force Geophysics Laboratory, Space Physics Division, Hanscom, U.S.A. The data for the current period from 1976 to 1985 were taken from Solar Geophysical Data book No. 487-Part I published in March, 1985. The sunspot data were obtained from the Solar Geophysical Data books issued by NOAA, U.S. Department of Commerce. A particular proton event was correlated with a sunspot group if the latitude and longitude of the proton flare coincide with that of the sunspot group.

3. Results

The results obtained from the study of proton events are listed under the respective heads as follows:

3.1. *Flux Distribution of Proton Events*

In order to determine the flux distribution of proton events, the proton fluxes were grouped into different convenient ranges (ΔI) and the frequency distribution of the proton events in those ranges (ΔN) were calculated. The values of $\log(\Delta N/\Delta I)$ were then plotted against the $\log I$ values, where I represents the mean values of the corresponding adopted ranges of the proton flux. The straight line graph in Fig. 1 showing

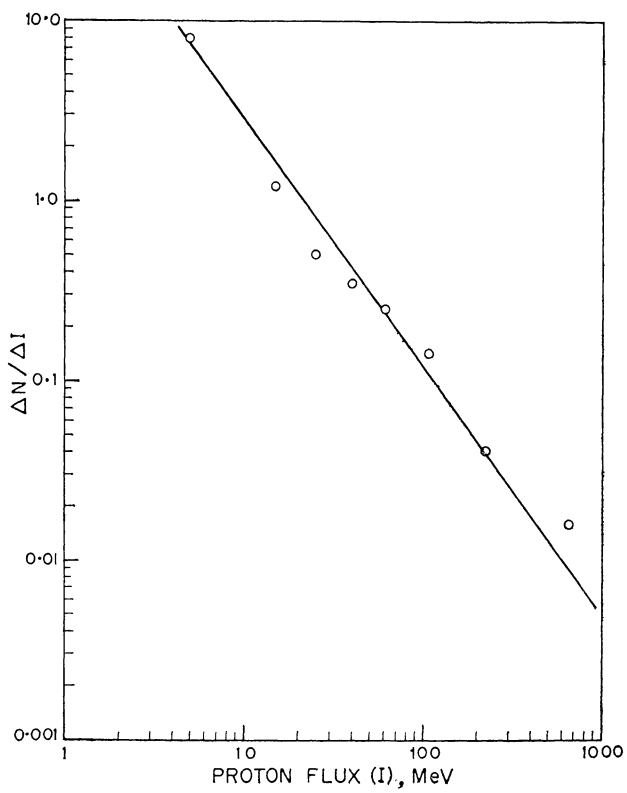

Fig. 1. Straight line giving the plot of logarithmic values of the number of proton events per unit flux interval with that of the proton flux.

the variation of $\log(\Delta N/\Delta I)$ with $\log I$ gives rise to the following relation

$$\frac{\Delta N}{\Delta I} = 69{\cdot}6 I^{-1.38}$$

3.2. *Relation between the Proton Flux and the Corresponding Rise Time*

The occurrences of proton events in different ranges of rise times (the time from the beginning to the maximum phase of the proton emission) have been plotted in Fig. 2. The rise times of proton flares may vary from 0 to 55 hours, but most of them display rise times within ten hours.

The histogram in Fig. 3 shows the number of occurrences of proton flares in different ranges of their durations. Most of the proton events have durations in the ranges of 15 to 25, 35 to 40 and 45 to 50 hours.

The ratio (r) of the rise time to the duration of each of the proton events, giving rise to the impulsive character of the events was determined individually.

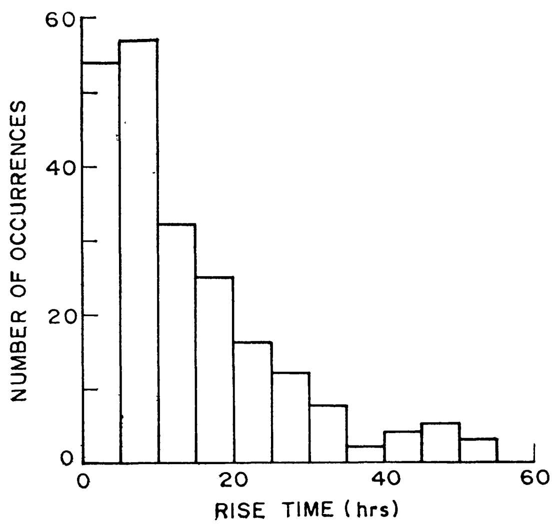

Fig. 2. Histograms showing the number of occurrences of proton events in different ranges of rise times.

The frequency distribution of 'r' values is displayed in Fig. 4 which shows that about 60% of all the 'r' values are between 0·1 and 0·3.

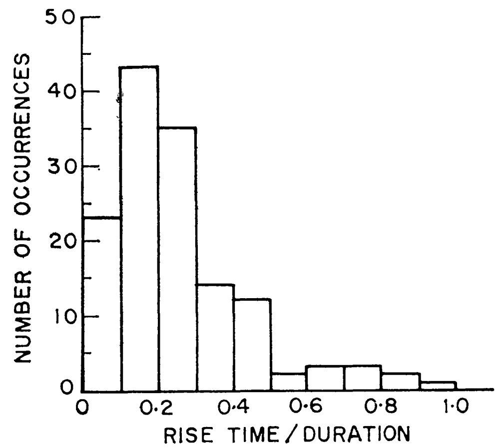

Fig. 4. Histograms showing the number of occurrences of proton events in different ranges of 'r' values.

The logarithmic values of the proton flux $(\log I)$ and the corresponding time rate of rise of the proton flux $(\log \Delta I/\Delta t)$ have been plotted as shown in Figure 5. The scatter diagram shows that these two quantities bear a linear relationship and, hence, the method of least squares was applied to obtain the following rela-

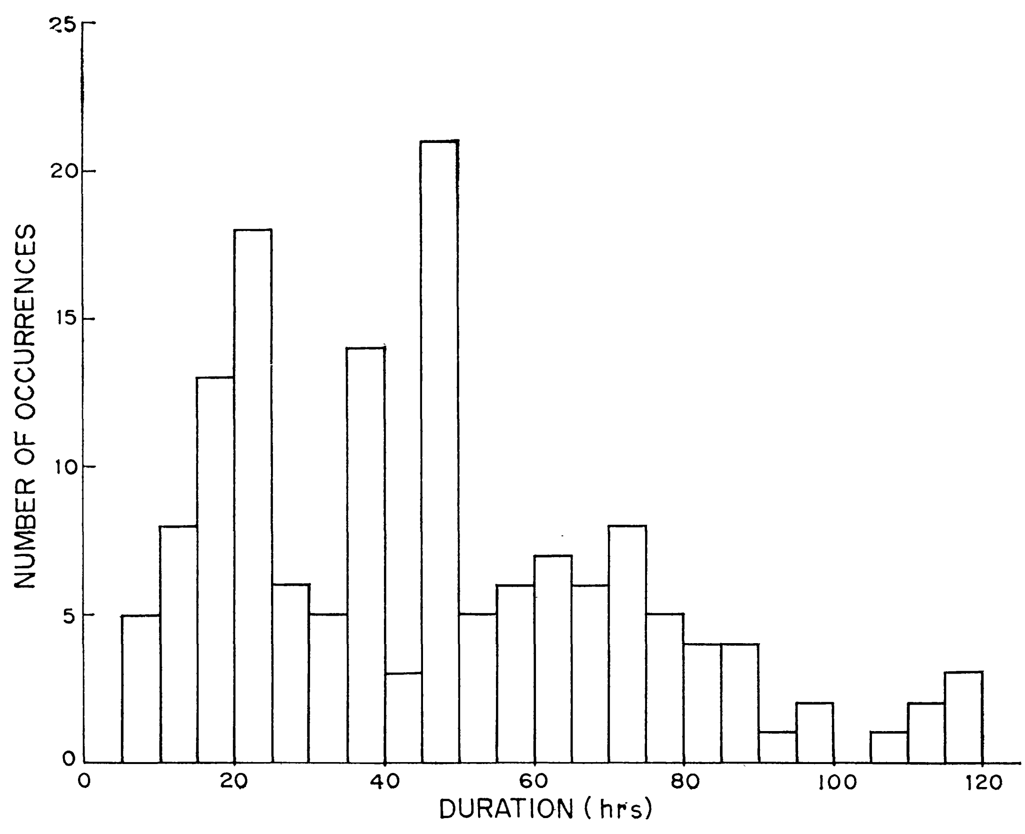

Fig. 3. Histograms giving the number of occurrences of proton events in different ranges of their durations.

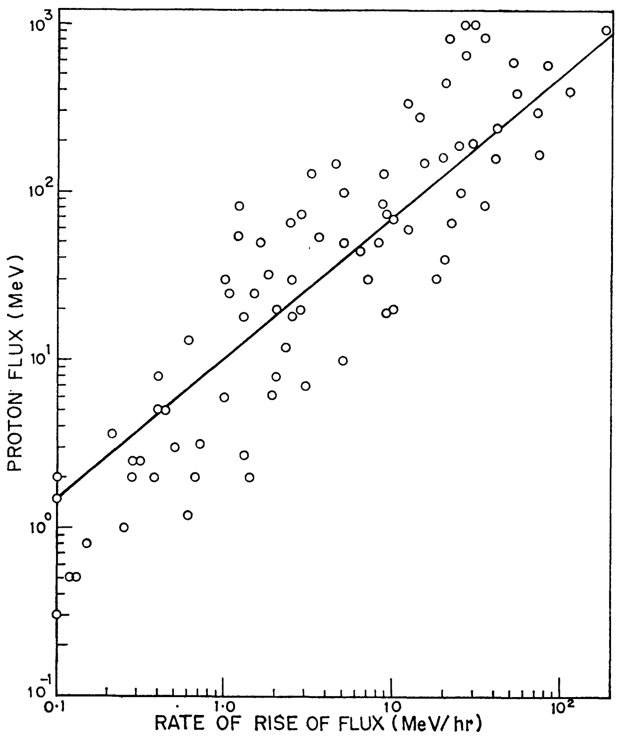

Fig. 5. Regression line showing the variation of proton flux with the respective rate of rise of flux values.

tionsship

$$\log I = 0{\cdot}83 \log \frac{\Delta I}{\Delta t} + 1{\cdot}00$$

which can be simplified to

$$\frac{\Delta I}{\Delta t} = 0{\cdot}06 I^{1\cdot 2} \tag{2}$$

3.3 *Solar Cycle Dependence of the Occurrences of Proton Events*

The occurrences of proton events on the solar disk during the period of one year were plotted against the respective year as shown in Fig. 6, giving rise to the solar cycle variation of the occurrences of proton flares. The occurrences of proton events follow more or less the phase of the solar cycle, which is obvious. But it is peculiar to note that the maximum number of proton events appear to occur during the 20th cycle peak, although the peak of this cycle is least pronounced compared to that of the 19th and 21st cycle.

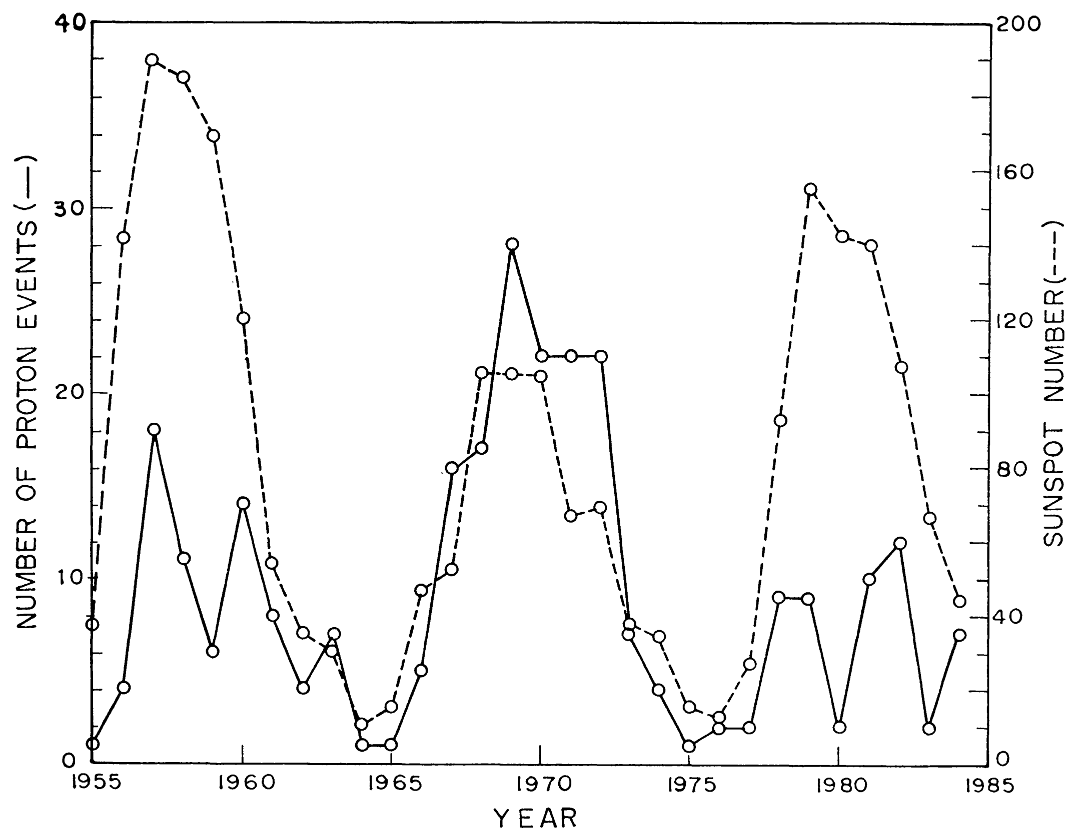

Fig. 6. Curves give the solar cycle variation of proton events. The dotted curve shows the yearly variation of sunspots and the solid curve that of the proton events.

3.4. *North – South and East – West Asymmetries*

The positions of the proton events on the solar disk were determined after knowing the positions of the related sunspot group. The asymmetries $(N-S)/(N+S)$ and $(E-W)/(E+W)$ were calculated from the north–south and east–west distribution of proton events; N, S, E and W represent the number of occurrences of proton events in the northern, southern, eastern and western hemispheres, respectively. The variation of these asymmetries with latitude as shown in Fig. 7 reveals that the proton events which were observed over the three consecutive cycles, appear to cluster preferably in the northern hemisphere. Again, they concentrate in the eastern part of the hemisphere at longitudes 0° to 30° and in the western part beyond longitude 30°.

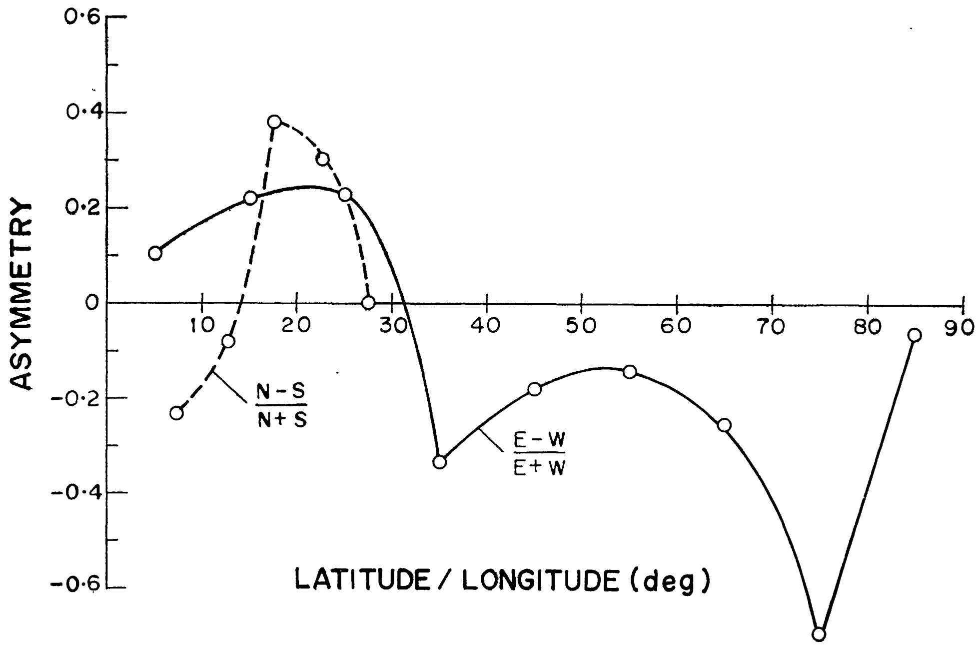

Fig. 7. Curves giving the variation of the N – S asymmetry (— — —) and E – W asymmetry (———) with the latitude and longitude of the proton events on the solar disk, respectively.

4. Discussion

The power law distribution of the proton fluxes as obtained in the previous analysis is similar to that of the sunspot magnetic fluxes and integrated intensity of Hα – flares (Das and Das Gupta, 1982, 1984), soft X-ray peak fluxes (Drake, 1971), microwave burst intensity (Kundu, 1980 and Kakinuma et al., 1969), the only difference being in the value of the exponent. The empirical relation (2) which connects the proton flux values with the rate of rise of flux will be helpful in determining the integrated proton flux values from the beginning of the event to the time the flux is required.

The solar cycle variation of proton events gives the interesting results that the maximum number of proton events occurs during the twentieth cycle which is least active compared to the preceeding and subsequent cycle. The mechanism of generation of proton flares does not perhaps depend on the magnetic field of the active region which is believed to be connected with that of Hα flares.

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