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STATISTICAL ANALYSIS FOR SOLAR PROTON EVENTS MEASURED BY GOES SPACECRAFT DURING THE PERIOD (1976–1990)

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ABSTRACT

During the period from January 1976 to January 1990 there were 81 solar proton flares affecting the solar-terrestrial environment, the events measured by GOES spacecraft at Geosynchronous orbit.
Proton fluxes are integral 5-minute averages for energies > 10 MeV, given in particle flux unit (pfu) where 1 pfu = 1 $p/cm^2 s^{-1} sr^{-1}$. The data are published in the comprehensive reports of "Solar-Geophysical Data" by NOAA, Boulder - Colorado, USA.
Statistical analysis was carried out for 81 solar proton events and their associated solar flares and active regions. The proton flux classified to seven levels from 10 to > 100.000 pfu. The delay time between the maximum flaring on the sun and the maximum proton flux of the event recorded by GOES has been taken into consideration.
Also, the correlation between the proton flux and X-ray and radio bursts, and optical importance of the associated flare was performed.

INTRODUCTION

Some recent researches dealing with solar proton events during the last three solar cycles were made by /1,2,3/ and the important results can be reported as follows :

1- The data of proton events occurring over the last three solar cycles consists of 120 events in which the events integrated flux exceeded 10^2 proton cm^{-2} for protons with energies above 10 MeV., and 140 events with integrated flux above 10^5 proton cm^{-2} and energies above 30 MeV.

2- The analysis of the data of the last three solar cycles 19, 20, and 21 gave a periodicity of almost 152 days in all the three cycles.

3- Cycle 21 had a very high maximum sunspot number and a very large integrated proton flux, but cycle 20 had lower sunspot maximum and lower total flux. However, cycle 21 had a sunspot number maximum between the values for cycle 19 and 20 but the integrated flux that was lower than that which was during either of the other two cycles.

4- Before the 21^{st} solar cycle, it was widely believed that the total proton flux integrated over a solar cycle was related to the maximum sunspot number of the cycle. But now, there is no evidence for a relation between solar cycle maximum sunspot number and the integrated proton flux.

The geomagnetic strom strength depends largely on the energy of the ejected plasma cloud, and since this depends on the energy released during the flare occurrence, the strength of the geomagnetic storm will subsequently depend on the energy of the associated flare. With this assumption, occurrence of geomagnetic storms is possible when the proton flare energy reaches a certain level. Below this energy level geomagnetic storms will not occur /4/.
Using data on the solar X-ray bursts in the two spectral bands 0.5-4 Å and 1-8 Å, it is found from /4/ reasonable linear correlations between the peak flux of solar X-ray bursts (associated with solar proton flares) and velocity of the associated interplanetary shock wave. The analysis showed also weak correlation between the peak flux burst and kp magnetic index of the associated geomagnetic storms.

The study of proton flares is particularly challenging because, as yet, there are no adequate theoretical models for the production of such high energies in the solar atmosphere.

DATA

All data used in this work represent optical, radio and X-ray observations, which published in "Solar-Geophysical Data", monthly bulletins issued by NOAA, Boulder - Colorado, USA.
During the period from January 1976 to January 1990 there were 81 significant solar proton flares affecting the solar-terrestrial environment, the events measured by GOES spacecraft at Geosynchronous orbit.
Proton fluxes are integral 5-minute averages for energies > 10 MeV, given in particle flux unit (PFU) where 1 pfu = 1 p/ $cm^2 s^{-1} sr^{-1}$.

ANALYSIS AND RESULTS

Statistical analysis was carried out for 81 solar proton events and their associated solar flares and active region. Table (1) contains the classification of the fluxes of proton flares occurring during the period under investigation. This classification proved to be useful in the detailed study of proton flares.

1. Association with Hα Flares :

The result of association study between the number of proton flare occurrences for each class of proton flux and different classes of Hα solar flare classification is investigated and tabulated in table (2).

Examination of table (2) indicates the following :

1. Most of proton flares occurred in sub-class 2B and 3B, and class F proton flares are rather rare phenomena.
2. The proton flares in class B are more associated (80%) than that in class N (18.6%) and class F (1.4%).
3. There are 11 events with unknown optical class.

2. Association with X-ray bursts :

The proton flares in our period were analysed for each class of proton flux with each sub-class of SESC X -ray classification /5/. The results are presented in table (3). From these analysis we can clearly notice that :

1- Proton flares in the X-class are more associated (56.8%) than that in M-class (38.3%) and C-class (1.2%).

2- There are three proton flares with unknown X-ray class (14 June 1983; 16 February 1984; and 25 March 1988).

3. Association with Radio bursts :

As in optical and X-ray classification, we studied the association of proton flare occurrences in each class of proton flux with each type of the radio bursts. The results are included in table (4). Which we can see that, the number of proton flare occurrences are more associated in type IV (48%) and type II (21%) and followed by type III (14%), but the associations in type I (10%) and type V (7%) are less frequent.
The tendency of proton flares ≥ 10 MeV, to be associated with type II and type IV reflects the mode acceleration of protons in the course of these two types of bursts.
Generally, the number of proton flare occurrences in the lower classes of proton flux are less than that in the higher classes.

CONCLUSIONS

The solar proton flares are mostly associated with the brilliant type B (80%) more than that with the normal type N (18.6%), or faint type F (1.4%) in the Hα flare luminosity classification. On the other

TABLE 1 Classification of proton flare fluxes

Class	Ranges of proton flare flux in pfu
R1	$50 > \phi \geq 10$
R2	$100 > \phi \geq 50$
R3	$500 > \phi \geq 100$
R4	$2000 > \phi \geq 500$
R5	$5000 > \phi \geq 2000$
R6	$10000 > \phi \geq 5000$
R7	$\phi \geq 10000$

ϕ; is the proton flux (protons/cm^2. sec. str.)

TABLE 2 Association between each class of proton flare flux and the different classes of Ha solar flares (Faint (F), Normal (N) or Brilliant (B)).

	SF	1F	2F	3F	4F	SN	1N	2N	3N	4N	SB	1B	2B	3B	4B	Unknown
R1	-	-	-	-	-	1	4	4	-	-	-	2	8	5	-	4
R2	-	-	-	-	-	-	-	1	1	-	1	-	5	5	-	3
R3	1	-	-	-	-	-	-	1	1	-	-	5	4	6	1	1
R4	-	-	-	-	-	-	-	-	-	-	2	-	1	1	1	2
R5	-	-	-	-	-	-	-	-	-	-	-	-	2	4	-	1
R6	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-
R7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Total	1	-	-	-	-	1	4	6	2	-	3	7	21	22	3	11
No.	1					13					56					
%	1.4					18.6					80					

TABLE 3 Associations of PF in each class of proton flux with each class of x-ray flares

	C	M	X	Unknown class	Total number
R1	1	15	10	1	27
R2	-	7	8	1	16
R3	-	8	13	-	21
R4	-	1	5	1	7
R5	-	-	7	-	7
R6	-	-	2	-	2
R7	-	-	1	-	1
total No.	1	31	46	3	81
%	1.2	38.3	56.8	3.7	

TABLE 4 Associations between different level of proton flux of the solar proton flares and various type bursts (I, II, III, IV, and V)

	I	II	III	IV	V	Total number
R1	2	5	5	13	2	27
R2	3	3	2	6	2	16
R3	1	6	3	9	2	21
R4	1	2	1	3	-	7
R5	1	1	-	5	-	7
R6	-	-	-	2	-	2
R7	-	-	-	1	-	1
total No.	8	17	11	39	6	81
%	10	21	14	48	7	

hand, the proton flares are more associated with the type X (56.8%) than that with the type M (38.3%) and type C (1.2%) in SESC X-ray classification.

The association of the class B in Hα flare classification with the number of proton flare occurrence is acceptable since that class B is always produced from active regions of a magnetically complex type i.e. of mixed magnetic polarities /6/. And this complexity of magnetic field configuration is the basic cause of the proton flares productivity. On the other hand, the association of number of occurrence of proton flares with the X-class in the SESC classification can be understood as follows, the X-class produced only at a higher energy and accompanied by a higher X-ray peak flux. From table (3) we notice that , the X-class (peak energy 10^{-1} erg.cm^{-2}.s^{-1} and X-ray peak flux greater than 10^{-4} Watt.m^{-2}). This level of energy and peak flux are most suitable for proton flare productivity.

In the microwave radio classification, the studied proton flares are more associated with type IV (48%) and type II (21%) than with type I (10%), type III (14%) and type V (7%).

The association of type IV and type II radio bursts with the number of proton flare occurrence can be easily understood; some accelerated particles are traped in coronal magnetic field and when the density of that particles is large enough, "Synchrotron radiation" is emitted in the radio continuum. Besides, the type II and IV bursts indicate the presence of expanding or fast moving coronal transients above the proton flare active region that probably have their origin in some instability where the acceleration process takes place. Types I, III and V seldom accompany proton flares. This is not due to the interplanetary propagation effects but rather to lack in production of interplanetary energetic protons in that types.

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