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Association of Solar Energetic Particle (SEP) Events with Sunspot Numbers

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ABSTRACT:*The study and understanding of Solar Energetic Particle (SEP) Events is very important for space scientists in order to understand the risks and hazards as well as to predict and take preventive actions. It is strongly believed that the probability of SEP event occurrence increases with solar activity represented by Sunspot number and hence the maximum probability is at Solar maximum. In this paper an attempt is made to associate the frequency of occurrence of SEP events with respect to the Sunspot numbers. A large data base from the year 1976to the year 2016is considered for this analysis. The results of this analytical study are presented in this paper.*

KEY WORDS: *Solar Energetic Particle, SEP event, Sunspot number, Probability association, Relative probability, Sunspot number month.*

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I. Introduction

Sun is an efficient particle accelerator and hence governs the energetic particles in the solar system. The space weather is defined by the solar energetic particles, high energy neutrals, coronal mass ejections and the shock waves due to CMEs.They determine the space weather conditions.

Solar Energy Particles (SEPs) with energies from few 10s of keV to few GeV are accelerated near the Sun. They are classified into two different types of events (i) impulsive events and (ii) gradual events. The gradual SEP events cause high risk to the health of humans in space and in future colonies of humans on other planets within the solar system since they accompany very high energies (> 10s of MeV). They are also hazardous to spacecrafts particularly for the sensitive electronic components and equipment and to the spacecraft elements exposed to spacelike thermal blankets and solar cells and solar cell interconnects. This in association with the effect of SEPs on space weather has generated a lot of interest in the study of SEPs particularly in the area of predicting them in advance by looking for associationof them with other events. For example, the ground level enhancements (GLEs) are due to very high energy SEPs (> 0.5GeV) passing through the Earth's atmosphere. The studies so far have indicated a strong association of SEPs with two important physical processes;(i) solarflares and (ii) interplanetary shock waves due to CMEs.The current state of understanding of this gradual SEP events can be found in (Desai and Geacalone) [1]

THEO[2] is an expert system developed by McIntosh in 1990 to predict the occurrence of solar flares of class X and M based on a statistical model and using McIntosh class of Sunspot groups. Subsequently many solar flare prediction systems were developed by Gallagher et al[3] in 2002, Nunez et al[4] in 2005, Wheatland[5] in 2005.

Presently there are two approaches namely physics based models and empirical models for the prediction of SEP events. Empirical models are largely driven by closed form equations derived from statistical analysis and in some cases use machine learning. They observe the associated events like flares intensity, location of the flare, radio observations etc. Owens et al. (2016) [6] compares the physics based and empirical modelsPresently the SEP event predictionfor the given set of drive parameters results in many false triggers. In order to decrease these false triggers, it may be useful to see the relative probability of SEPs when associated with Sunspot numbers.

It is generally believed that the relative probability of SEP event occurrence is at Solar maximum. This conclusion is natural when one looks at the plot presented in Figure 1.1. The top plot shows the Yearly number of SEP events for the Solar cycles 22 and 23, from March 1986 to January 2008. The bottom plot shows the yearly mean Sunspot number for the same period. This paper attempts to establish this relative probability by means of statistical analysis of data over a large number of years.

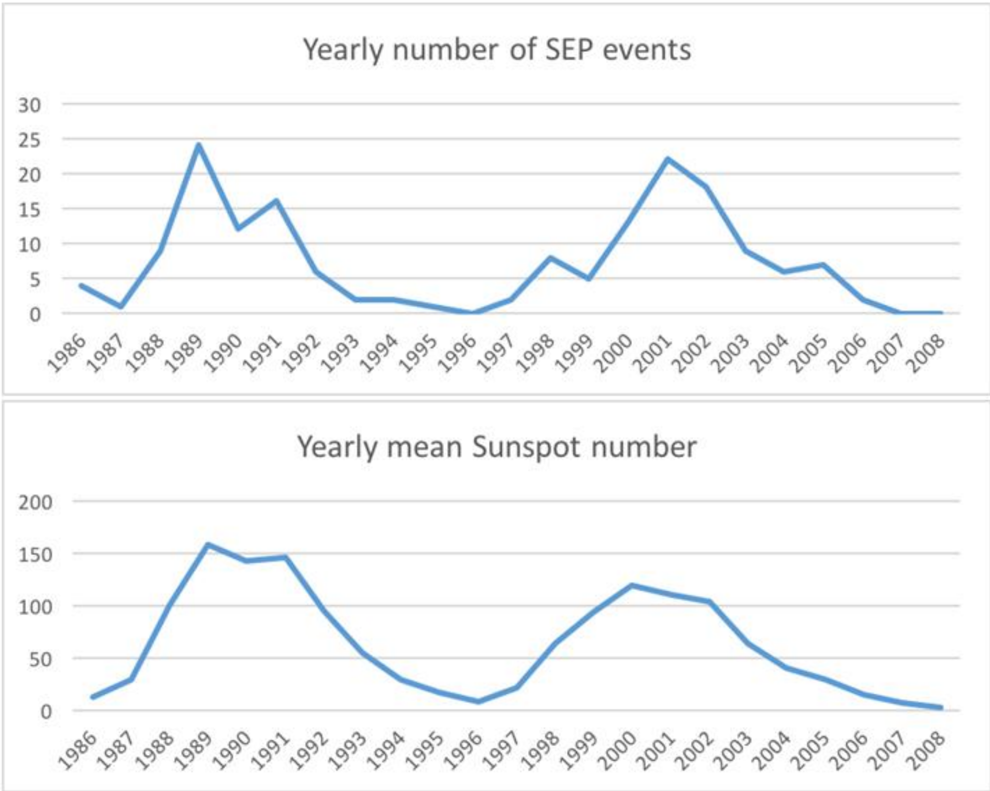

Figure 1.1. Yearly number of SEP events and yearly mean Sunspot number for Solar cycles 22 and 23

II. Data Used

The monthly mean Sunspot number data used for analysis is given in Table 2.1. This table is based on the observed (definitive and provisional) monthly mean sunspot numbers from WDC-SILSO, Royal Observatory of Belgium, Brussels (sidc.oma.be/silso/home)[7].The data is available for the years between 1976 and 2016as prepared by Bureau of Meteorology Space Weather Services last updated 01 Jan 2017 12:49 UT.

The SEP event data is obtained from Space Weather Prediction Centre of NOAA[8]. This data contains, apart from other details, a list of SEP events with the starting time of the event, time at which the maximum proton flux occurred and the maximum proton flux. The Proton fluxes are integral 5-minute averages forenergies > 10 MeV, given in Particle Flux Units (pfu), measured by GOESspacecraft at Geosynchronous orbit (near 1 AU): 1 pfu = 1 p/sq. cm-s-sr. SWO defines thestart of a proton event to be the first of 3 consecutive data points withfluxes greater than or equal to 10 pfu. The end of an event is the last timethe flux was greater than or equal to 10 pfu[9].

Different detectors, onboard various GOES spacecraft, have taken the datasince 1976. These proton data were processed by SWPC using various algorithms. Though the Sunspot data is available from the referred source from the year 1749, our analysis in this paper is carried out from the year 1976 to 2016 due to the unavailability of SEP data before 1976. About 492 events were recorded over the 41 years of data. For a statistical analysis on a monthly basis a sample size of 492 is fairly adequate.

III. Methodology And Analysis

The aim of this analysis is to find the relative probability of the occurrence of SEPs with respect to the Sunspot number. During the period of 1976 – 2016 the minimum monthly mean Sunspot number is 0 and the maximum is 284.5. In other words, there are months in this 41 years when there were no sunspots. Similarlythere are months with 284 sunspots over this 41-years. These values are arranged in to 11 ranges, each range with an interval of 25. The range selection is only a matter of convenience to get uncongested graphical representation in terms of plots and hence has no scientific significance. The number of months in which a particular range of Sunspot numbers occurred are added together and called "Sunspot months". During all the Sunspot months in a particular range the number of occurrences of SEP events are added together and are associated to the respective Sunspot months. It may be noted here that only presence of an SEP event is considered without the peak flux and duration of the event as the focus is on the probability of occurrence. Figure 3.1. shows the plot of number of Sunspot months and Number of SEP events for a given range of Sunspot numbers. The ratio of number of SEP events occurred to that of the number of Sun spot months is a good indicator for the relative probability. If this ratio is plotted with respect to the range of Sunspot numbers, the relative probability can be visualized. Figure 3. 2. Gives the plot of the ratio of number of SEP events to the number of Sunspot months against the range of Sunspot numbers. By general belief that all the events on sun increase from the solar minimum to the solar maximum, one would expect the relative probability of SEP events also occur at the highest range of Sunspot number i.e. > 275. But the interesting observation is that the relative probability does not occur at the higheststrange but at a range of 175 to 200. The Sunspot number range of 175 to 200 is further divided into 5 ranges with an interval of 5 in order to narrow down the range at which the relative probability of SEP occurrence peaks.

Figure 3.3. and Figure 3.4. give the similar plots as in Figure 3.1. and figure 3.2. respectively but over a narrow range. It is observed the peak ratio and hence the peak of relative probability occurs in the Sunspot number range of 180 -185. It may be noted that the sample sizes here already got reduced to single and double digits. Further narrowing the range for finer analysis would not yield any meaningful results.

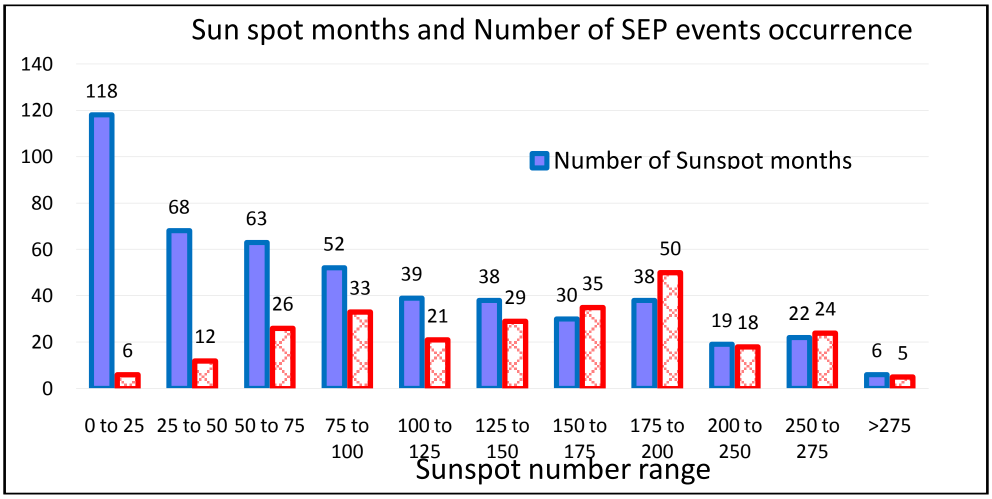

Figure 3.1. Number of Sunspot months and Number of SEP events for a given range of Sunspot numbers

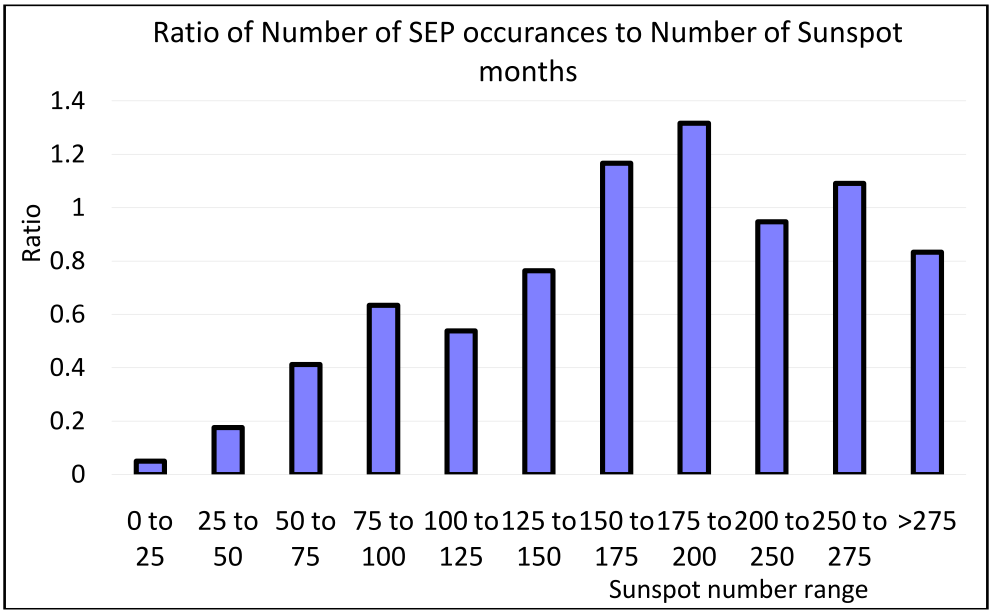

Figure 3. 2. Ratio of number of SEP events to the number of Sunspot months against the range of Sunspot numbers

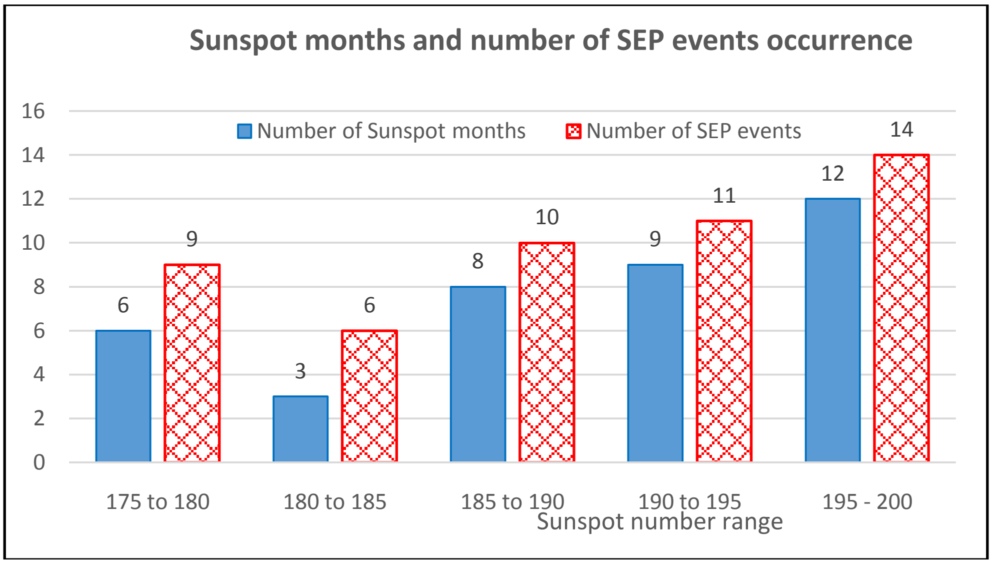

Figure 3.3. Number of Sunspot months and Number of SEP events for Sunspot numbers range 175 – 200

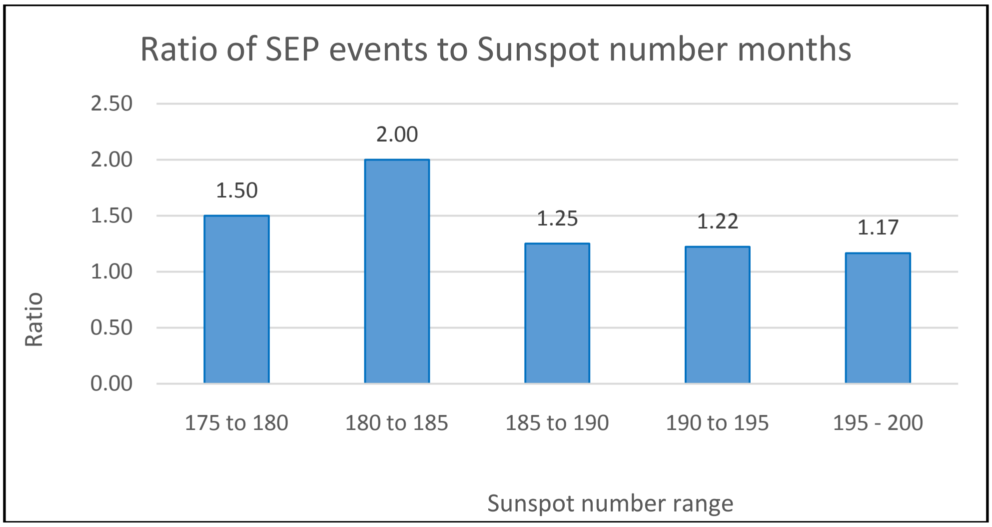

Figure 3. 4. Ratio of number of SEP events to the number of Sunspot months against the range of Sunspot numbers (175 – 200)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1976	11.9	6.4	31.5	27.3	18.2	17.9	2.9	24.1	20.0	29.7	7.9	22.3
1977	23.8	33.3	13.0	19.0	27.0	54.9	30.6	43.0	62.4	62.1	41.6	61.4
1978	73.7	132.6	108.4	141.2	117.1	134.6	99.7	82.4	195.7	177.1	138.5	173.9
1979	235.9	194.7	195.3	143.7	190.3	211.7	225.7	201.4	266.9	263.6	259.5	249.6
1980	226.1	219.4	178.7	232.2	254.7	222.7	192.9	191.7	219.6	233.3	209.5	246.9
1981	156.6	189.9	196.6	225.3	194.7	131.6	205.3	242.5	245.3	216.2	186.0	195.4
1982	149.8	230.9	221.1	170.3	119.3	163.7	139.4	161.9	167.4	134.3	127.5	169.0
1983	115.5	73.1	88.7	109.6	132.5	131.5	108.9	96.0	69.9	72.5	45.7	45.6
1984	74.8	110.2	116.7	90.4	96.9	65.1	55.7	35.0	22.6	12.6	26.5	21.4
1985	17.8	20.7	16.9	20.4	32.4	28.3	39.9	10.1	4.3	22.0	17.9	15.8
1986	2.8	27.9	13.8	22.4	16.1	0.6	18.1	9.9	5.1	40.1	15.4	5.8
1987	9.8	3.4	17.4	46.0	39.1	18.8	38.2	47.9	42.2	63.4	48.8	29.1
1988	70.5	45.4	91.2	108.8	74.2	124.3	131.4	139.4	142.7	156.5	156.8	231.2
1989	210.1	208.7	170.4	166.3	195.4	284.5	180.5	232.0	225.1	212.2	238.2	211.4
1990	227.4	171.8	191.7	189.7	175.2	153.3	191.1	252.1	169.1	199.4	178.8	197.1
1991	195.3	240.3	197.0	197.6	166.9	224.7	240.2	240.8	168.9	197.1	159.5	212.6
1992	198.3	230.7	151.0	142.2	94.3	98.5	114.2	91.9	94.0	133.4	129.6	122.0
1993	81.4	127.8	102.4	94.4	78.8	69.6	80.4	62.5	31.2	71.1	48.2	68.4
1994	84.9	54.9	47.5	27.4	29.8	39.7	50.6	34.3	40.5	67.1	29.5	32.2
1995	32.6	45.8	46.3	21.6	19.4	22.5	20.4	18.2	15.7	30.6	14.0	14.9
1996	13.3	7.7	12.6	6.8	7.6	16.5	11.8	19.7	3.0	0.7	24.9	14.0
1997	7.4	11.0	12.1	23.0	25.4	20.8	12.9	35.7	59.7	32.8	50.4	55.5
1998	44.5	50.2	82.0	70.6	74.0	90.5	96.7	121.1	132.0	78.5	97.3	119.2
1999	86.0	98.0	103.5	93.6	149.6	207.2	173.5	142.3	106.3	168.7	188.3	116.8
2000	133.1	165.7	217.7	191.5	165.9	188.0	244.3	180.5	156.0	141.6	158.1	143.3
2001	142.6	121.5	165.8	161.7	142.1	202.9	123.0	161.5	238.2	194.1	176.6	213.4
2002	184.6	170.2	147.1	186.9	187.5	128.8	161.0	175.6	187.9	151.2	147.2	135.3
2003	133.5	75.7	100.7	97.9	86.8	118.7	128.3	115.4	78.5	97.8	82.9	72.2
2004	60.6	74.6	74.8	59.2	72.8	66.5	83.8	69.7	48.8	74.2	70.1	28.9
2005	48.1	43.5	39.6	38.7	61.9	56.8	62.4	60.5	37.2	13.2	27.5	59.3
2006	20.9	5.7	17.3	50.3	37.2	24.5	22.2	20.8	23.7	14.9	35.7	22.3
2007	29.3	18.4	7.2	5.4	19.5	21.3	15.1	9.8	4.0	1.5	2.8	17.3
2008	4.1	2.9	15.5	3.6	4.6	5.2	0.6	0.3	1.2	4.2	6.6	1.0
2009	1.3	1.2	0.6	1.2	2.9	6.3	5.5	0.0	7.1	7.7	6.9	16.3
2010	19.5	28.5	24.0	10.4	13.9	18.8	25.2	29.6	36.4	33.6	34.4	24.5
2011	27.3	48.3	78.6	76.1	58.2	56.1	64.5	65.8	120.1	125.7	139.1	109.3
2012	94.4	47.8	86.6	85.9	96.5	92.0	100.1	94.8	93.7	76.5	87.6	56.8
2013	96.1	60.9	78.3	107.3	120.2	76.7	86.2	91.8	54.5	114.4	113.9	124.2
2014	117.0	146.1	128.7	112.5	112.5	102.9	100.2	106.9	130.0	90.0	103.6	112.9
2015	93.0	66.7	54.5	75.3	88.8	66.5	65.8	64.4	78.6	63.6	62.2	58.0
2016	57.0	56.4	54.1	37.9	51.5	20.5	32.4	50.2	44.6	33.6	21.4	18.9

Table 2.1. OBSERVED MONTHLY SUNSPOT NUMBERS

IV. Conclusion

An attempt is made in this analysis to establish the relative probability of the Occurrence of SEP events with respect to the Sunspot number. As the data base is quite large spreading over 41 years with a sample size of 492, this analysis shall hold good in future also. The interesting point to note is that the relative probability is not peaking at the highest Sunspot range, but at a range of 175 – 200. On further analysis it is found that the peaking occurs at a Sunspot number range of 180 – 185.

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References

[1]. Desai, M., and Giacalone, J. Large Gradual Solar Energetic Particle Events, Living Rev. Sol. Phys. 13 (3), 1 – 132, 2016, DOI: 10.1007/s41116-016-0002-5
[2]. McIntosh, P.S. The classification of sunspot groups, Sol. Phys., 125, 251-267, 1990, DOI: 10.1007/ BF00158405.
[3]. Gallagher, P.T., Y.J. Moon, H. Wang. Active region monitoring and flare forecasting. Sol. Phys., 209 (1), 171-183, 2002, DOI: 10.1023/A:1020950221179.
[4]. Nunez, M., R. Fidalgo, M. Baena, R. Morales. The influence of active region information in the prediction of solar flares: an empirical model using data mining. Ann. Geophys., 23 (9), 3129-3138, 2005, DOI: 10.5194/angeo-23-3129-2005.
[5]. Wheatland, M.S. A statistical solar flare forecast method. Space Weather, 3 (7), S07003, 2005, DOI: 10.1029/2004SW000131.
[6]. M. J. Owens, H. E. Spence, S. McGregor, W. J. Hughes, J. M. Quinn, C. N. Arge, P. Riley, J. Linker, and D. Odstrcil. Metrics for solar wind prediction models: Comparison of empirical, hybrid, and physics-based schemes with 8 years of L1 observations. Space weather, 6, S08001, 2008, DOI: 10.1029/2007SW000380
[7]. http://www.sws.bom.gov.au/ Solar/1/6
[8]. ftp://ftp.swpc.noaa.gov/pub/indices/ SPE.txt
[9]. Kurt V et al, Statistical analysis of solar proton events, AnnalesGeophysicea, 2004, SRef-ID: 1432-0576/ag/2004-22-2255

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