Anatomization of Solar Energetic Particles (SEPs) during Solar Cycles 23-24

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Introduction

Solar events comprise many drastic and explosive phenomena due to the variability in the solar magnetic field with solar cycles of 11 years. This variability in the magnetic field of the sun triggers several events which result in the release of highly energetic particles such as protons, electrons, ions up to Fe, neutrons and some γ- rays. Solar Energetic Particle (SEP) events observed in the interplanetary medium are composed of electrons, protons, and heavier ions up to Fe (and higher) with energy ranging from a few dozen keV to several GeVs. SEP events are caused by particle acceleration caused by solar flares, interplanetary shocks caused by Coronal Mass Ejections (CMEs), or shocks linked with co-rotating interaction regions. The accelerated particles then swirl across the heliosphere, following the interplanetary magnetic field (IMF). We have studied major SEPs of solar cycles 23(~106 SEPs) and 24(~46 SEPs) associated with high-speed coronal mass ejections and established their relationship with SXR (soft X-Rays) class flares. From the detailed study of data from 1996-2020, we have found that these major SEPs are linked with CMEs advancing in IP space with high speed (>1500 km/s). The flares associated with these SEPs are of class X and M with the highest value of class X.20 on 02/04/2001,21:32 UT and X.28/3b on 04/11/2003, 19:38 UT in solar cycle 23 while in solar cycle 24, the flare of maximum intensity X9.3 on 06/09/2017, 11:53 UT was observed. At the peak of the solar cycles, solar activity increases tremendously ejecting a large amount of plasma and energetic particles in the IP space. The energetic particle (E>10 MeV) directly affects the magnetosphere and space system technology [1,2,3]. SEPs are mainly associated with accelerated coronal mass ejections of broad angular width (>60^0) [4] accompanied by large solar (>M1) flare causing geomagnetic storms within 1-4 days on the Earth's magnetosphere. SEPs are classified into four categories, (S1-pure impulsive, S2-Impulsive + Shock, S3 – Weak gradual with Impulsive seed, S4 – Pure gradual). The development of empirical and/or semiempirical statistical relationships between the features of SEP events and the observable attributes of the parent solar events is a critical component for decoding their characteristics. From the analysis of major SEPs associated with CMEs and solar flares, we conclude that SC23 consisted of a high number of intensified flares. The correlation between the variables shows the dependency of observational properties of CMEs and flares on the solar energetic particles. Figure 1 illustrates an idealized profile of a proton event [5]. Figure 2 (a, b) illustrates the relationship between proton peak flux for E> 10 MeV and flare intensity. The Pearson's correlation is cc = 0.44816 in SC23 and cc = 0.25461 in SC24. Figure 2(c) shows the relationship between the proton peak flux (pfu) for E> 10 MeV and the speed of CMEs. The Pearson's correlation shows a moderate correlation (cc=0.48) in SC23 and weak correlation (cc = 0.13) in SC24.

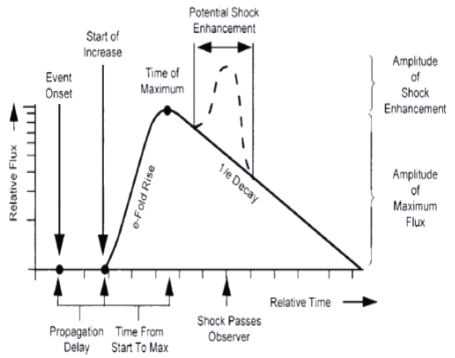

Figure 1. Idealized profile of proton event. [5]

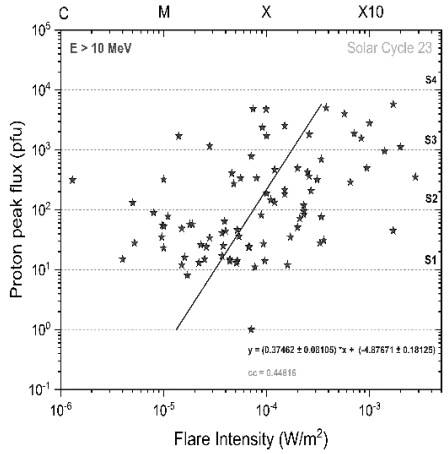

Figure 2(a) scatter plot between proton peak flux(pfu) and flare intensity(W/m^2) for low energy channel (E>10MeV) for SC23

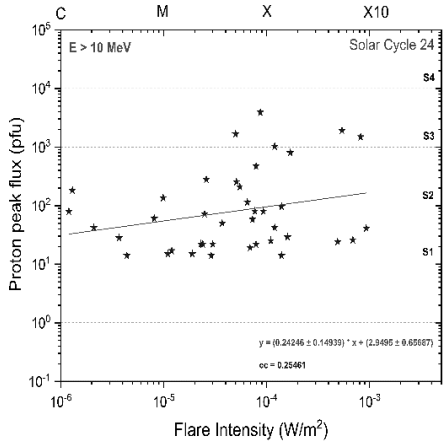

Figure 2(b) scatter plot between proton peak flux(pfu) and flare intensity(W/m^2) for low energy channel (E>10MeV) for SC24

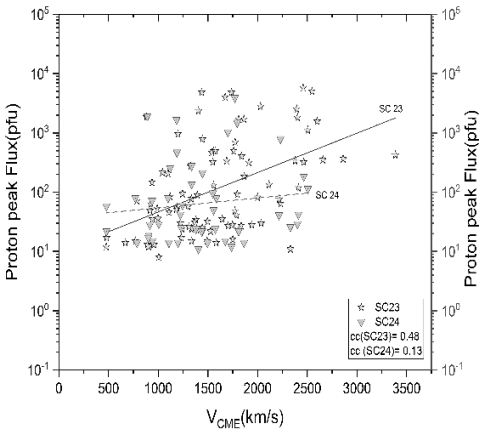

Figure 2(c) Scatter plot and linear fit between proton peak flux and v_{CME} for SC23 and SC24.

From the analysis of major SEPs associated with CMEs and solar flares, we conclude that SC23 consisted of the high number of major solar energetic particles associated with intensified solar flares and high-speed CMEs in comparison to SC24 in the energy channel E > 10 MeV. The correlation between the variables shows the dependency of observational properties of CMEs and flares on the solar energetic particles.

References

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