Abstract

The high-energy protons from solar energetic particle (SEP) events present a hazard to space systems: damage to science instruments/electronics/materials or to astronauts. A reliable estimate of the high-energy proton environment is critical to assure mission success. Important characteristics of an SEP event are fluence, peak flux, energy spectrum, time to reach the peak flux, time to reach peak dose, and properties of the cumulative dose profile after an event starts. All of these characteristics are important to understand in order to design space missions properly for both robotic and human missions.

Because of the unpredictable and sporadic nature of SEP events, statistical models are often used to represent the SEP parameters described above. In a study by Jun et al. (2007), the statistics of event fluences, durations, and time intervals between events were investigated using the then-available historical SEP dataset obtained from the instruments onboard the IMP-8 spacecraft. Since then, a more comprehensive SEP dataset based off of IMP-8 and GOES called Reference Data Set Version 2.0 (RDSv2.0) has become available covering the SEP events up to Year 2015 under a framework of the European Space Agency’s (ESA’s) Solar Energetic Particle Environment Modelling (SEPEM) project (Jigjitt et al., 2018). The main objectives of this statistical study of SEP events are two-fold: First, the statistics of peak fluxes, event fluences, durations, and time intervals will be re-visited by using RDSv2.0; Second, the statistical analyses of flux and dose timing will be performed using the same dataset RDSv2.0. The results of this study will address the statistical properties of all key parameters for designing a spacecraft or a human mission where the SEP environment is an important consideration.

1. SEP Background Subtraction Methodology

1. Select only fluxes that are considered “background” with a static threshold

Using thresholds specified for each energy channel, exclude fluxes that are too high (SEPs) to be background.

2. Create a distribution of background fluxes for time periods of 3 Bartels Rotations (BR) and each channel individually

3. Calculate the mean and standard deviation of each distribution

μ = average background flux

4. Use the background in step 3 as a changing threshold, iterate steps 1 – 3; Calculate background for each day using the previous 27 days

5. Set all flux less than μ + 3σ to zero; assume μ + background flux and subtract from RSDv2.0 data set to get SEP flux plots below

4. Results: SEP Event Statistics

Time to Peak Flux Compared to Time to 10%, 50%, and 90% Dose

Cumulative Distributions: Flux and Dose Timing

Relationship with Peak Flux: Fluence and Total Dose

Above left: Fluxes selected as background (black) are put into a distribution for each period of 3 BR for an initial estimate of the background μ and σ.

Above right: After iterating, the final background flux values (μ) for every day in the RSDv2.0 data set. The error bars (σ) indicate the amount of fluctuation expected in the background. μ and σ were calculated using the 27 days prior to each day.

2. Automated SEP Event Start and Stop Times

SEP START in specified channel – each channel treated independently:

- Require flux above background (non-zero flux) in specified channel
- Require any 2 other channels to also see an increase (3 channels total)
- Require a consecutive increase in 3 channels for 4 hours
- Allow 50 minutes worth of gap in that initial period
- If all requirements are met, then the SEP event start time is recorded as the first point where conditions are satisfied

SEP END in specified channel:

- If specified channel and 2 other channels do not record an increase during the allowed gap, SEP event ends at last point where requirements were met

3. Identification of Dose-Significant SEP Events

The top and bottom plots show the hourly dose rates inside of a sphere of 10 g/cm². The distribution shows that a sphere of 10 g/cm² was calculated for the total flux in the RSDv2.0 data set. Each channel is treated independently, and colors correspond to the energy range in MeV. In some cases, lower energy channels may identify a single SPE, while higher energy channels may indicate multiple SPEs in the same time period.

Left: Solid lines indicate identified SEP event start times and dashed lines indicate SEP event stop times. Each channel is treated independently, and colors correspond to the energy range in MeV. In some cases, lower energy channels may identify a single SPE, while higher energy channels may indicate multiple SPEs in the same time period.

Above: The statistics calculated in this study are tabulated for the 10 largest SEPs in the RSDv2.0 dataset. SEP Event Date, Onset Time, SEP Event Duration, SEP Event Fluence, Total Dose, and Cumulative Distributions: SEP Event Duration, Distribution: Time Intervals between SEP Events, and Cumulative Distributions: Flux and Dose Timing are shown for the 10 largest SEPs in the RSDv2.0 dataset. SEP Event Date, Onset Time, SEP Event Duration, SEP Event Fluence, Total Dose, and Cumulative Distributions: SEP Event Duration, Distribution: Time Intervals between SEP Events, and Cumulative Distributions: Flux and Dose Timing are shown for the 10 largest SEPs in the RSDv2.0 dataset.

Example distributions of SEP event duration (top left), time intervals between events (top right), and fluence (bottom left) calculated in this study are shown for channels 3 and 8. Each energy channel was treated independently, resulting in different numbers of SEP event days. The cumulative distributions are shown as insets for duration and time interval between events.

Cumulative distributions for the timing parameters in this study. The insert table lists the percent of SEP events that have reached peak flux, peak dose rate, 10%, 50%, and 90% dose within 0.5, 1, 1.5, 2, 5, and 10 hours. SEP events behave similarly for time to peak flux, peak dose rate, and 50% dose.