
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 database 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 (SEPSEM) project (Jiggens 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 revisited 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

1.1 Selection of Background Flux for CH8 (32.56–76.25 MeV)

Selection of Background Flux for CH8 (32.56–76.25 MeV)

Above Left: Fluxes selected as background (black) are put into a distribution for each period of 3 h 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 RDSv2.0 dataset. 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.

1.2 Characteristics of SEP Event

1.2.1 SEP Background Subtraction Methodology

- 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
- Create a distribution of background fluxes for time periods of 3 Bartels Rotations (BR) and each channel individually
- Calculate the mean and standard deviation of each distribution μ and σ = average background flux μ and σ = measure of fluctuations expected in the background
- Use the background in step 3 as a changing threshold, iterate steps 1–3; Calculate background for each day using the previous 27 days
- 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

1.3 What is the SEP START in specified channel?

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

After SEP event starts, allow a gap (dwell time) of up to 3 hours

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

2. Automated SEP Event Start and Stop Times

2.1 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

After SEP event starts, allow a gap (dwell time) of up to 3 hours

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 Aluminum for 1989 calculated from the total flux in the RSDv2.0 data set (black) and 1999 (blue). The bottom plot shows the hourly dose rate for 1989 calculated from background-subtracted flux (orange). Even though many events occurred, only a subset of these events resulted in an increase in dose above background.

It was found that SEP start and stop times derived from Channel 8 (66.13 – 95.64 MeV, green lines on top plot) successfully identified the dose-significant events (10 g/cm2) and appropriate start and stop times to capture the full event dose.

4. Results: SEP Event Statistics

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

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

Above: To time Peak Flux vs Time to 10% (left), 50% (middle), and 90% (right) Dose. The red lines indicate a 1:1 correspondence.

4.2 Cumulative Distributions: Flux and Dose Timing

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.

4.3 Relationship with Peak Flux: Fluence and Total Dose

Relationship with Peak Flux: Fluence and Total Dose

Left: Fluence shows a clear relationship with peak flux for all channels (CHB shown). Right: Total dose in CHB (66.13 – 95.64 MeV) vs peak flux shows a linear relationship in log scale.

5. Conclusions

The SEP Study of Solar Particle Events in Flux and Dose

The study confirms the effectiveness of the SEP background subtraction methodology by comparing the results to the RDSv2.0 dataset. The methodology is shown to be reliable and accurate for identifying SEP events.

6. Acknowledgments

Acknowledgments of the funding agencies and the role of the funding agencies are not provided in the abstract.