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Superposed epoch analysis of solar energetic particle events observed in solar cycle 25

G. U. Farwa[1], N. Dresing[1], R. Vainio[1]

[1] Department of Physics and Astronomy, 20014 University of Turku, Finland
"e-mail(speaker): ghulam.u.farwa@utu.fi"

Solar energetic particle (SEP) events are major outbursts of energetic charged particle radiation from the Sun. These events are related to solar flares and fast coronal mass ejections (CMEs). SEP events consist of energetic protons, electrons and heavier ions and can cause solar radiation storms. SEP events have a direct space weather impact on electronics of space vehicles, satellites and radiation threat to humans on space missions and aircraft flying high in polar routes. SEPs can also interact with the ionosphere causing absorption of high frequency radio waves resulting in distortions of radio communications and radar systems. Hence reliable warning systems, which are currently not yet in place, are required to predict the occurrence and intensity of SEPs events, and mitigate its impact.

This work is an effort to contribute towards the development of reliable space weather forecast systems. We analyzed a sample of 45 SEP events occurring in early solar cycle 25 between November 2020 and May 2023 using data from multiple spacecraft including Solar Orbiter, near-Earth spacecraft (SOHO and Wind), STEREO A, BepiColombo, and Parker Solar Probe. We make use of time intensity profiles of >25-MeV protons and ~100-keV and ~1-MeV electrons and perform superposed epoch analysis on normalized time-intensity profiles of the SEP events of the sample. We separate the events into those that are magnetically well-connected (longitudinal separation $\leq$ 35°) or poorly-connected (longitudinal separation > 35°) to the source region at the Sun.

We fit the normalized time-intensity profiles with exponential and power-law models in order to describe the mean behavior of the rise and decay phases of the SEP events and compare the obtained parameters among the different particle energies and observing sectors.

We find that the power law model fits the superposed means better for both rise and early decay phases of all SEP events. This analysis will be helpful in predicting an average SEP event under certain source conditions.