

Predicting Solar Energetic Particle in the Inner Heliosphere Using Machine Learning and PSP/ISOIS Data

Spiridon Kasapis¹, Tate Hutchins¹, Hameedullah Farooki¹, Manuel Cuesta¹, Lengying Khoo¹, Sungmin Pak¹, Robert Czarnota², Jamie Rankin¹, Jamey Szalay¹, Zigong Xu³, Georgios Livadiotis¹, Nikolaos Sarlis⁴, David McComas⁴

¹Princeton University, Princeton, United States, ²Rowan University, Glassboro, United States, ³California Institute of Technology, Pasadena, United States, ⁴National and Kapodistrian University of Athens, Athens, Greece

Solar activity, including coronal mass ejections and solar flares, can accelerate vast populations of high-energy charged particles, leading to solar energetic particle (SEP) events that pose risks to astronauts, spacecraft electronics, and, in extreme cases, technological infrastructure on Earth. Most previous machine-learning (ML) approaches to SEP prediction have focused on forecasting geoeffective events using measurements from Earth-orbiting spacecraft or missions located near the Sun–Earth L1 point. However, extending SEP prediction capabilities throughout the heliosphere is critical for enabling future exploration missions to Mars and beyond. In this work, we use extreme ultraviolet (EUV) observations from the Atmospheric Imaging Assembly (AIA) aboard the Solar Dynamics Observatory (SDO) to predict energetic particle intensities measured by the Integrated Science Investigation of the Sun (ISOIS) instruments on the Parker Solar Probe (PSP) at various locations along the ecliptic plane between the Sun and Earth. The proposed deep-learning framework extracts image features from SDO/AIA 171 Å observations using convolutional layers, incorporates spacecraft trajectory information, and processes the combined representation with transformer and fully connected layers. The model produces a continuous estimate of the energy-weighted average particle intensity, which is subsequently thresholded to generate a binary classification indicating whether the intensity exceeds a predefined operational level. The best-performing model achieves a probability of detection of 0.76, a true skill score of 0.47, an F1 score of 0.47, a false alarm rate of 0.65, and a precision of 0.35. These results are comparable to those obtained by ML models focused on geoeffective SEP prediction, demonstrating the potential for ML-assisted forecasting of SEP events throughout the inner heliosphere.