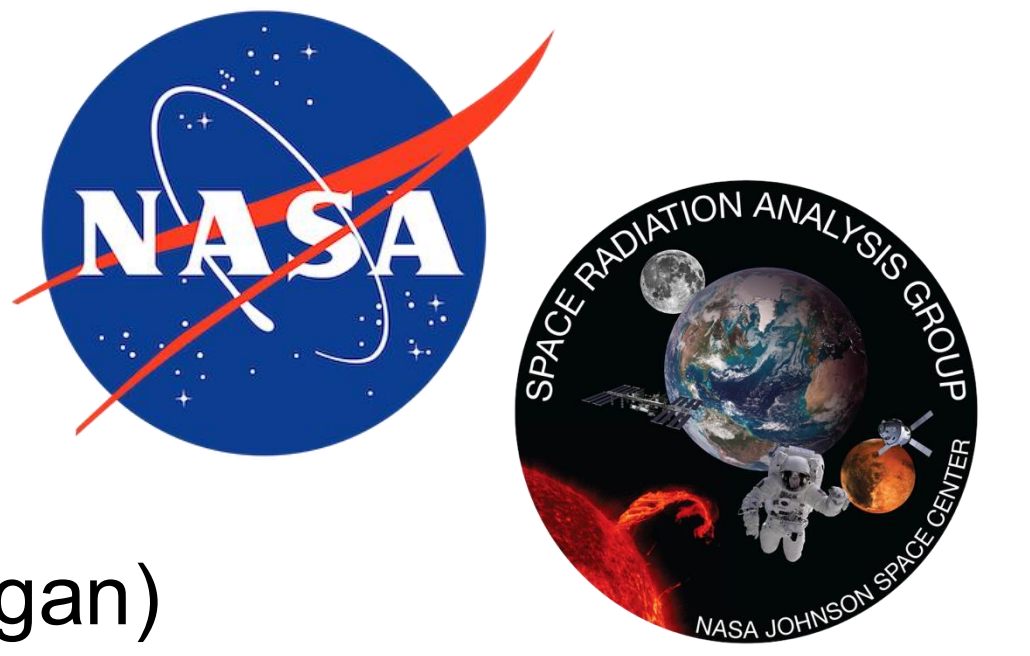




The CLEAR SEP Benchmark Dataset

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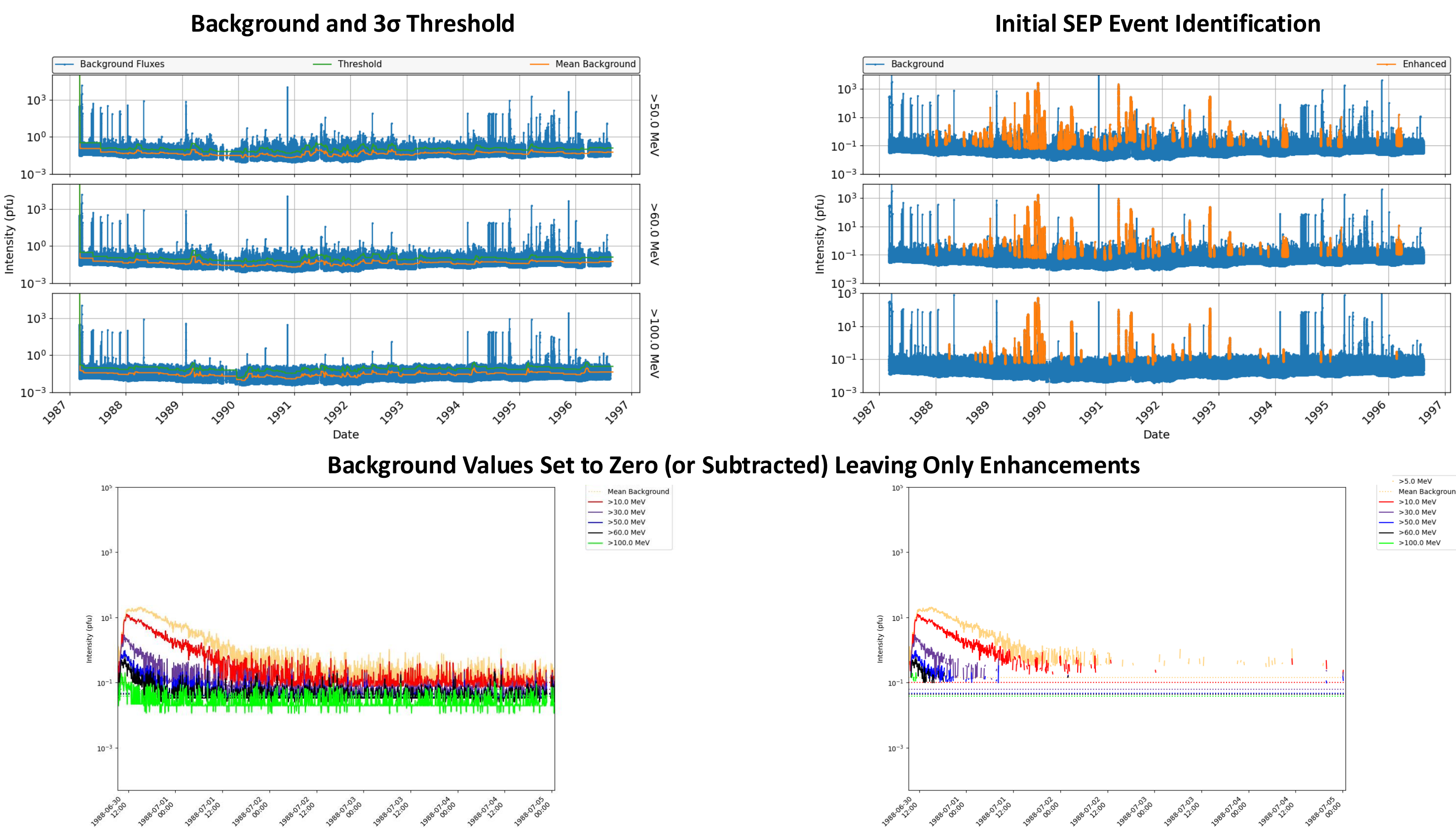
The goals of the CLEAR benchmark dataset are to provide a high-quality solar energetic particle (SEP) dataset for model development and validation, apply consistent and reproducible SEP event definitions with FetchSEP, provide extensive information about each SEP including comprehensive proton flux quantities and flare, CME, radio, etc., associations from historical SEP lists, and automated list generation for reproducibility and ease of updating.

Automated, Consistent, and Reproducible SEP Analysis with FetchSEP

FetchSEP is composed of two primary modules: `idsep`, `opsep`. Together, they identify SEP enhancements above particle backgrounds, calculate SEP event characteristics, and incorporate associated eruption information from SEP event lists in the literature. The FetchSEP package provides scripts to enable any user to recreate the CLEAR SEP Benchmark Dataset. GitHub: <https://github.com/ktindiana/fetchsep>

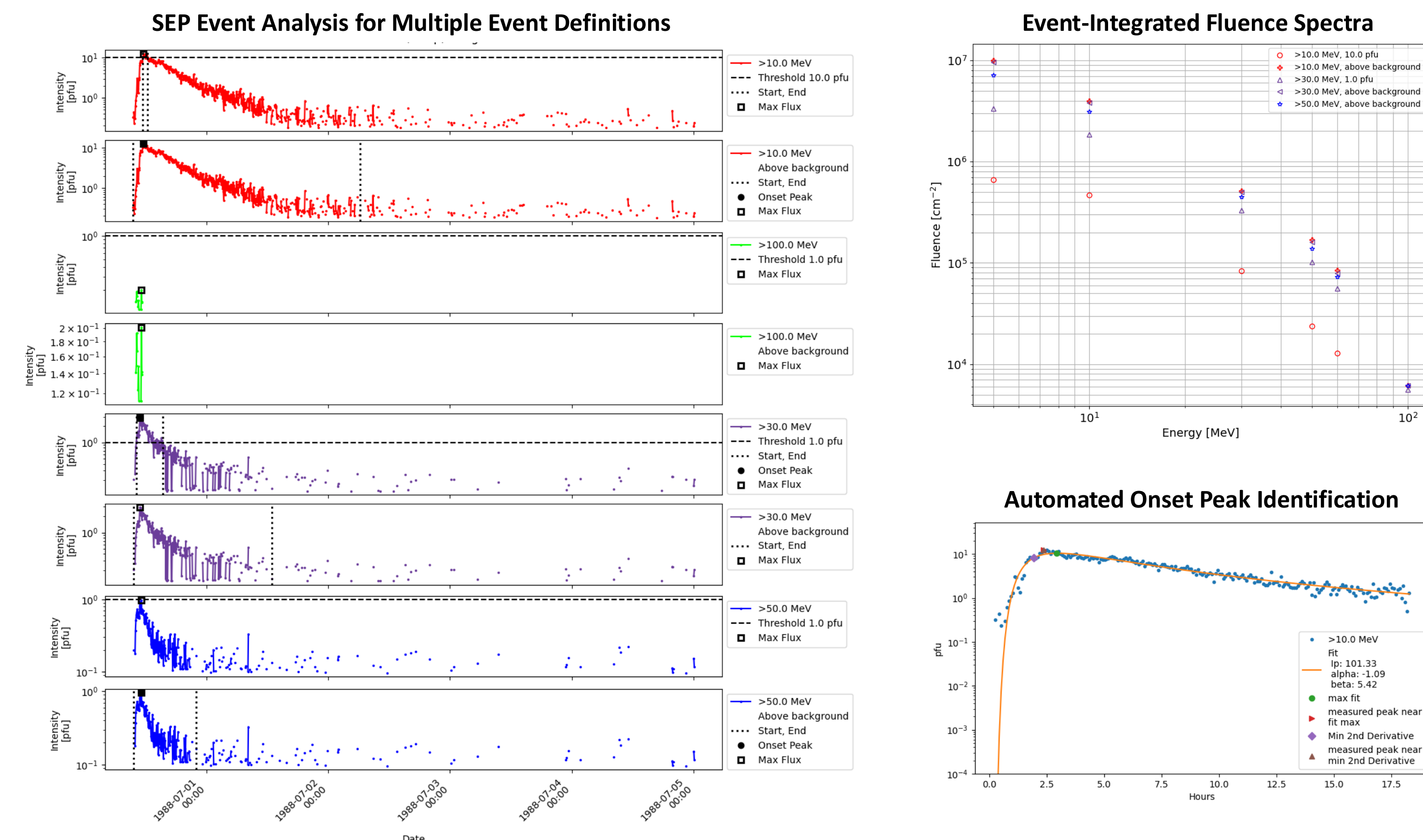
IDSEP

`idsep` works in an iterative manner to cleanly identify the particle background and enhancements above background due to SEP events. `idsep` outputs the mean background and the expected level of variation within the background for every timestep and provides approximate start and end times of SEP events above background.



OPSEP

`opsep` analyzes individual SEP events by applying specific SEP event definitions and calculating SEP parameters. Event definitions include static thresholds applied to specific energy channels (for example, > 10 MeV, 10 pfu) and the identification of SEP events above background levels. SEP lists from the literature are integrated into `opsep` to provide contextual information for historical SEP events. An automated method identifies onset peaks, when possible.



Contextual Information from Historical SEP Lists

Four SEP lists that were used to provide associated contextual information for the source eruptions for each SEP event, as available. The lists were converted to machine-readable formats and then supplemented, whenever possible, with NOAA science X-ray flare values, CDAW and DONKI CME parameters. Machine-readable versions of the lists are publicly available in the FetchSEP repository: <https://github.com/ktindiana/fetchsep/tree/main/fetchsep/reference>

SRAG SEP list: Carefully curated by Steve Johnson (SRAG), spanning Solar Cycle 22 to the present. Most complete for larger events that exceed SRAG's operational thresholds but includes many smaller events. Many types of contextual information are included with flare, CME, radio, and SEP values and timing derived from GOES. This list was used as the primary source of associations in the CLEAR dataset and is a good standalone SEP list in its own right.

25 MeV SEP list: Compiled by Ian Richardson from 1967 to the present (1986 - 1997 used for the CLEAR dataset). This list was derived from IMP and SOHO, which have lower backgrounds compared to GOES, and therefore contains many smaller events, supplementing the SRAG list.

Cane et al. (2010) list: Spans 1997 to 2006 and contains flare, CME, and Type III radio information along with approximate times of the source eruption and the following proton event (JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, A08101, doi:10.1029/2009JA014848, 2010).

Ian Richardson's (2025) SOHO/STEREO list: The version used in this work was provided directly by Ian and is consistent with <https://link.springer.com/article/10.1007/s11207-026-02614-4>. This list contains flare, CME, and radio information and particle intensities at SOHO and STEREO.

CLEAR SEP Benchmark Dataset

Proton information is calculated by FetchSEP from GOES data spanning 1986 to 2025. Associated flare, CME, and other contextual information is extracted from carefully curated historical lists. SEP event definitions are defined according to the needs of human spaceflight operations of the NASA Space Radiation Analysis Group (SRAG) as well as scientific interest:

- >10 MeV, 10 pfu (SWPC, SRAG EVA)
- >100 MeV, 1 pfu (all SRAG operations)
- >30 MeV, 1 pfu (situational awareness)
- >50 MeV, 1 pfu (situational awareness)
- Enhancement above background for >10, >100, >30, >50 MeV

Operational SEP Event List 1986 to 2025

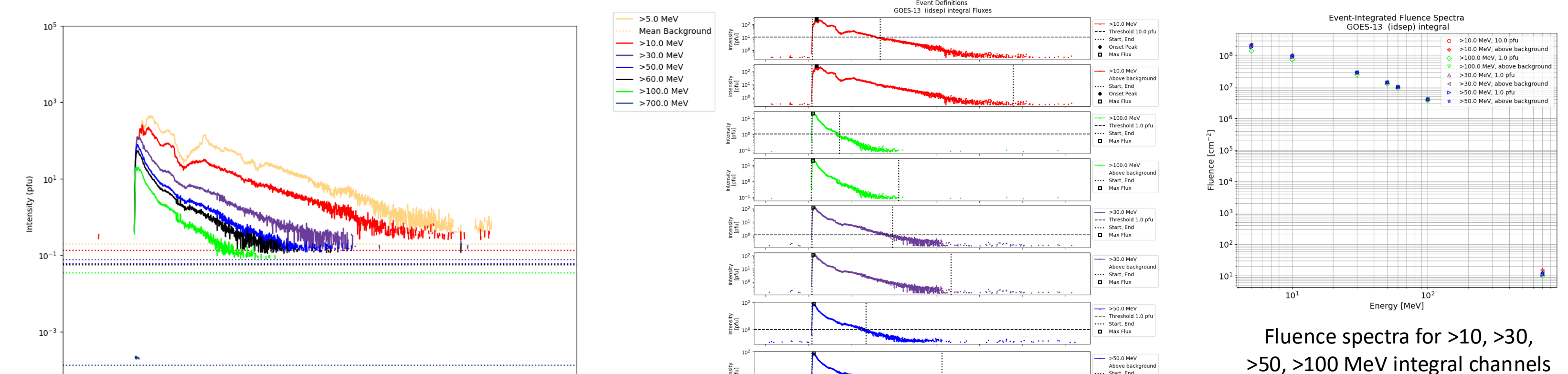
GOES-06 to GOES-18 integral fluxes provided by NOAA were used as-is, retaining the original flux values but setting fluxes identified as background to zero. **The operational list is best used for statistical analysis, development and validation of models with the goal of predicting operational values, and as a historical record of operational values.** Of identified >10 MeV SEP event, 91% include flare, CME, etc contextual information.

Event Definitions	Number of Events	With Associations
>10.0 MeV 10.0 pfu	263	263
>10.0 MeV above background	532	484
>100.0 MeV 1.0 pfu	88	88
>100.0 MeV above background	162	159
>30.0 MeV 1.0 pfu	257	252
>30.0 MeV above background	353	338
>50.0 MeV 1.0 pfu	160	158
>50.0 MeV above background	290	279

Table 1: Number of SEP events per event definition in the Operational SEP List in the CLEAR SEP Benchmark Dataset Version 2.0.

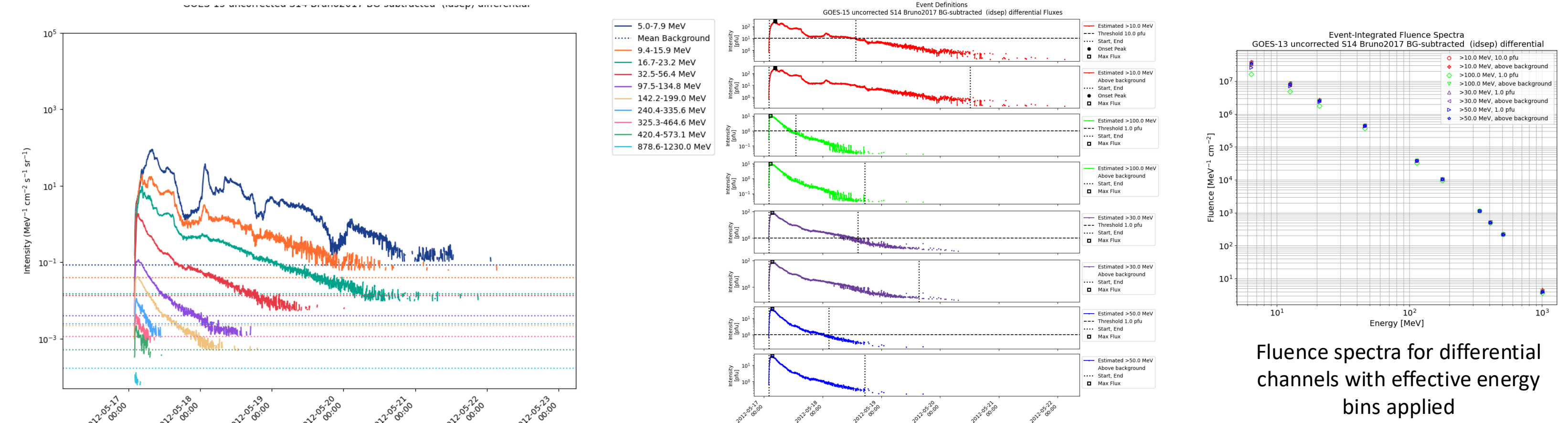
Operational SEP Event List

May 17, 2012 GOES integral fluxes with background set to zero



Energy-Bin Calibrated SEP Event List

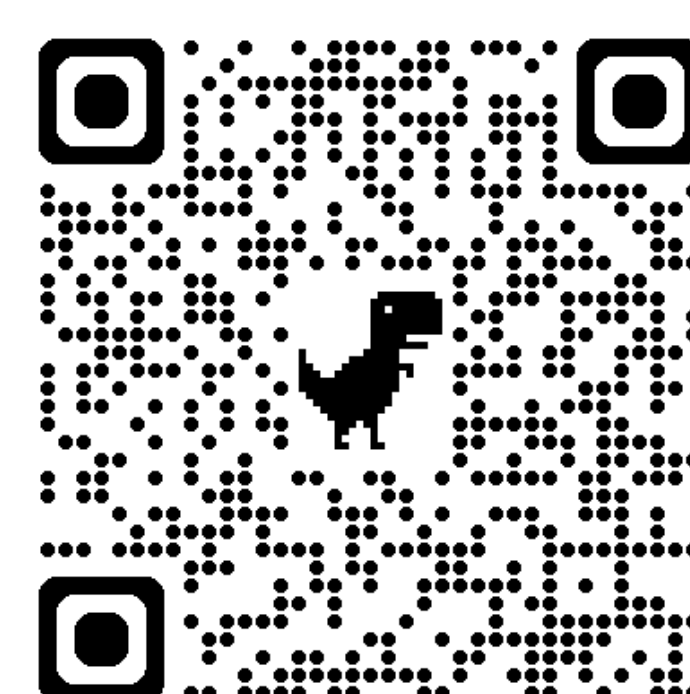
May 17, 2012 GOES uncorrected differential fluxes with background subtraction and effective energy bins from the literature



Energy-Bin Calibrated SEP Event List 2010 to 2020

The energy-bin calibrated list uses uncorrected differential fluxes provided by NOAA which were then background subtracted. Calibrated energies from the literature (Sandberg et al. 2014, Bruno 2017) were applied to the GOES differential channels then the integral energy channels (> 10, > 30, > 50, >100 MeV) were estimated. These calibrated energies were only available for GOES-13 and GOES-15, restricting the dataset to the time period covered by these satellites. **The energy-bin calibrated list provides a more accurate representation of the SEP energy spectrum and is best used for scientific studies, model development and validation for scientific purposes, and dosimetry calculations.** The list contains 98 SEP events, 93 of which have solar source eruption information (95%).

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CLEAR SEP Benchmark Dataset v2.0

Core SEP event lists, supporting products, and documentation for the CLEAR benchmark dataset. SEP events identified above operational thresholds for >10, >100, >30, and >50 MeV and above GOES detector background. The lists contain values from the primary GOES spacecraft at the time of the SEP event.

Core Products

Operational List
Integral GOES fluxes as is from NOAA archives; primary list for model development and validation against historical operational values (GOES-06 to GOES-18, Jan 1986–Sep 2020).
@ GOES_integral_PRIMARY1986-02-03 2025-09-10_sep_events.csv (1.04 MB)

Energy-bin Calibrated List
Differential, background-subtracted, cross-calibrated GOES fluxes for science and dosimetry studies; integral fluxes estimated from calibrated channels (GOES-13 and GOES-15, 2010–2020).
@ GOES_differential_energy_bin_calibrated_PRIMARY2010-06-02 2017-09-20_sep_events.csv (502.58 KB)

Code & Provenance

The CLEAR benchmark lists and supporting products are generated using the FetchSEP tools (described for identifying SEP elevations and analyzing individual events).
@ fetchsep-code repository (GitHub)
@ CLEAR Benchmark v2.0 tagged release

For more this page highlights the two primary CLEAR SEP lists and the full dataset. Future updates may add direct links between individual rows and the key plots generated for each event.