Code to Calculate Operational Values from SEP Data and Models

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Approach to Calculating SEP Values for this Challenge

- **SEP measurements depend on:**
  - **The instruments with which they are taken**
  - **Choices made during post-processing**
- Values are reported here for multiple spacecraft and data sets:
  - GOES-15 corrected EPEAD fluxes from the west-facing detector
    - Differential channels
    - Integral channels
  - GOES-13 corrected EPEAD fluxes from the west-facing detector
    - Differential channels
    - Integral channels
  - ESA's SEPEM (RSDv2) calibrated data set extending from 1974 – 2015
  - The SEPEM data set with a background-subtraction applied using a method developed at SRAG
- **Measurements display a range of values and model performance should be considered in the context of that range**

Approach to Calculating SEP Values for this Challenge

- **SEP event definitions are selected to align with those used operationally by the Space Radiation Analysis Group (SRAG) when supporting the International Space Station (ISS) Mission Control**
  - **Threshold:** >10 MeV proton flux exceeds 10 pfu (1/[cm^2 s sr])
    - **Consequence:** Awareness that proton levels are rising and provide support to Mission Control if an EVA is planned
  - **Threshold:** >100 MeV proton flux exceeds 1 pfu
    - **Consequence:** 24/7 support of Mission Control as proton levels can cause increased radiation dose behind shielding
  - SRAG currently monitors GOES-13 >10 MeV and > 100 MeV integral channels
  - Event end when 3 consecutive data points (15 minutes) fall below 0.85*threshold
    - Definition is somewhat arbitrary and was defined to keep the SRAG alarm code from retriggering as the proton flux decays slowly away around the threshold levels
    - >100 MeV fluxes below 1 pfu will not cause significant increase in dose behind shielding, so the part of the event above these levels is the most important to quantify

Code used to Calculate SEP Operational Quantities – Also for use with your model

- A user-friendly python 3 code was developed by Kathryn Whitman (Kathryn.Whitman@nasa.gov) to calculate the values requested for the SEP Modeling Challenge.
- **This code is sent along with this presentation to all SEP modelers so that the exact choices and methodology for determining the SEP values is transparent to all.**
- If the code is run with GOES-13 integral channels, the output will exactly match that generated by the SRAG operational alarm code.

- **Additional intention of this code:** For models that produce SEP time profiles, this code can be used to calculate exactly the same values in exactly the same way as data.
- Users may input their own data set (e.g. model output or data with special post-processing, such as background subtraction)
- Users may define their own threshold, e.g. >50 MeV, 10 pfu, to control event start and end
- Note: The code is not smart enough to handle multiple SEP events in a row – please contact Katie if you want to use the code for a specific event and run into problems; Updates and modifications will be ongoing and made public

Code to Calculate SEP Operational Quantities

- The code, operational_sep_quantities.py, does the following for a single SEP event:
  1. Creates “data” and ”output” directories

  2. Automatically downloads GOES-8 to GOES-15 data for requested time periods into “data”
     - User must match spacecraft to requested time period

  3. To use SEPEM data, the user must first manually download and unzip file (URL in code) into ”data” directory. The code will then break up the data set into yearly files for faster reading.

  4. Searches for data gaps (e.g. -999, assumes any negative flux is a data gap) and fills in the missing data by applying a **linear interpolation with time**
     - Zero flux is treated as a valid value as model code may have real zero values

  5. If user selects differential channels, code will estimate >10 and >100 MeV fluxes using **power-law interpolation across the energy bins**

Code to Calculate SEP Operational Quantities

- The code, operational_sep_quantities.py, does the following for a single SEP event:
  6. Calculates threshold crossing times, peak flux, peak time, rise time (onset to peak), event end, and duration
     - Calculates all for >10 MeV, 10 pfu and >100 MeV, 1 pfu thresholds; will additionally calculate for a user-input threshold
     - **An event ends when three consecutive data points fall below 0.85*threshold**
     - Peak flux is the highest flux measured between event start and end times
  7. Calculates event-integrated fluence of original channels (integral or differential) as well as event-integrated fluence corresponding to >10 MeV and >100 MeV fluxes (estimated if the original channels were differential)
  8. Fluences and event values are saved to files in “output” directory
  9. Shows useful plots with start and end times identified (**close plots for program to continue**)

To Run the Code (Copy-paste for Mac)

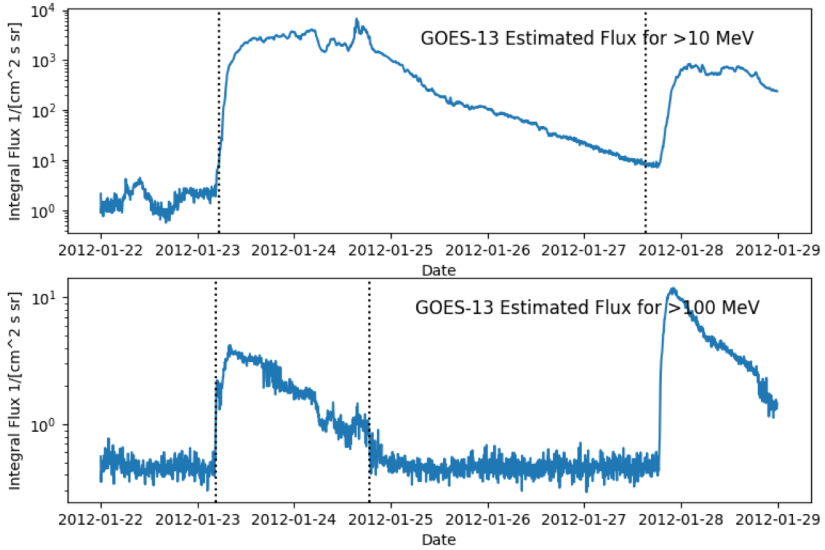
For Macs, I prefer using Homebrew. If you don't have homebrew, you may install with:
`/usr/bin/ruby -e "$(curl -fsSL https://raw.githubusercontent.com/Homebrew/install/master/install)"`

1. Install python3.
   - If you have a mac and use homebrew, you may use this command in the terminal:
     `brew install python`
2. Install additional libraries matplotlib, wget, scipy
   - For Mac, type in the terminal:
     ```
     pip3 install matplotlib
     pip3 install wget
     pip3 install scipy
     ```
3. If you try to run the code and get an error related to certificates, you may need to also run:
   `pip3 install certifi`
4. Run the code in terminal while inside the directory containing the code (try python if python3 doesn't work):
   `python3 operational_sep_quantities.py --StartDate 2012-05-17 --EndDate 2012-05-20 --Experiment GOES-13 --FluxType integral --showplot`
5. You may type `python3 operational_sep_quantities.py --help` to see all of the possible input.

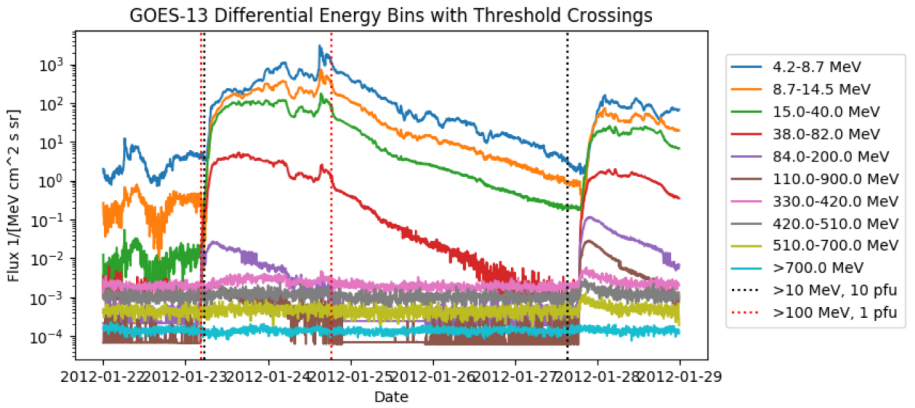
Example Run and Output – January 23, 2012

```
kwhitman$ python3 operational_sep_quantities.py --StartDate 2012-01-22 --EndDate 2012-01-29 --Experiment GOES-13 --FluxType differential --showplot
Checking that paths exist: data and output
Checking that the requested data is present on your computer.
Reading in data files for GOES-13.
Extracting fluxes for dates: 2012-01-22 00:00:00 to 2012-01-29 00:00:00
Checking for bad data values and filling with linear interpolation with time.

There is a data gap for time 2012-01-25 16:25:00 and energy 4.2 - 8.7 MeV. Filling in missing value with linear interpolation in time.
The first good value previous to gap is on 2012-01-25 16:20:00 with value 57.995
The first good value after to gap is on 2012-01-25 16:30:00 with value 58.943
Filling gap at time 2012-01-25 16:25:00 with interpolated flux 58.468999999999994
… (More output for corrections to other energy channels but left out to save space)
Finished checking for bad data.

Converting differential flux to integral flux for >10MeV.
Converting differential flux to integral flux for >100MeV.
Calculating threshold crossings and SEP event characteristics.
Flux      Threshold    Time Crossed         Peak Flux            Peak Time            Rise Time  End Time            Duration
>10 MeV   10 pfu       2012-01-23 05:25:00  6740.972728430253   2012-01-24 15:30:00  1 day, 10:05:00    2012-01-27 15:15:00  4 days, 9:50:00
Calculating threshold crossings and SEP event characteristics.
Flux      Threshold    Time Crossed         Peak Flux            Peak Time            Rise Time  End Time            Duration
>100 MeV   1 pfu       2012-01-23 04:35:00  4.2245477057861   2012-01-23 08:05:00  3:30:00    2012-01-24 18:40:00  1 day, 14:05:00
Extracting fluxes for dates: 2012-01-23 05:25:00 to 2012-01-27 15:15:00
=====Calculating event fluence for event defined by >10 MeV, for 2012-01-23 05:25:00 to 2012-01-27 15:15:00
Extracting fluxes for dates: 2012-01-23 05:25:00 to 2012-01-27 15:15:00
Event-integrated fluence for >10.0 MeV: 5028965340.697082 1/[cm^2]
Event-integrated fluence for >100.0 MeV: 4867346.341940369 1/[cm^2]
Extracting fluxes for dates: 2012-01-23 04:35:00 to 2012-01-24 18:40:00
=====Calculating event fluence for event defined by >100 MeV, for 2012-01-23 04:35:00 to 2012-01-24 18:40:00
Extracting fluxes for dates: 2012-01-23 04:35:00 to 2012-01-24 18:40:00
Event-integrated fluence for >10.0 MeV: 4254464976.467603 1/[cm^2]
Event-integrated fluence for >100.0 MeV: 3486739.9315438424 1/[cm^2]
Plotting estimated integral fluxes with threshold crossings.
Plotting fluxes in original energy bins. Any bad data points were interpolated. Lines indicate event start and stop for thresholds.
Plotting event-integrated fluence spectrum.
```

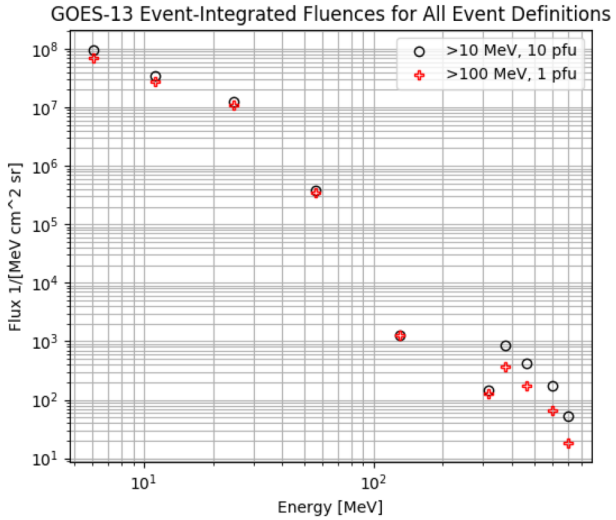
Example Run and Output – January 23, 2012



Integral fluxes estimated from the differential channels using power law interpolation across energy bins. Event start and end times for each threshold indicated by vertical black lines.



Plot of differential channels with the event start and end times for >100 MeV, 1 pfu threshold indicated by vertical black lines.



Event-integrated fluence of differential channels for the start and end times defined by >100 MeV, 1 pfu threshold. HEPAD channels could benefit from background-subtraction, especially when increase is small.

Output Files from Code – Fluence for Thresholds

Output files containing the **event-integrated fluence for each of the integral or differential energy bins**, as specified by user. There is a fluence file that corresponds to each threshold definition. For example, for GOES-13 spacecraft differential channels for Jan. 23, 2012 event:

>10 MeV, 10 pfu: fluence_GOES-13_differential_gt10_2012_1_23.csv
>100 MeV, 1 pfu: fluence_GOES-13_differential_gt100_2012_1_23.csv

	A	B	C	D
1	#Event defined by >10	10 pfu; start time 2012-01-23 05:25:00	end time 2012-01-27 15:10:00	
2	#Elow	Emid	Ehigh	Fluence 1/[MeV cm^2 sr]
3	4.2	6.044832504	8.7	97655914.41
4	8.7	11.2316517	14.5	34676630.66
5	15	24.49489743	40	12262732.19
6	38	55.82114295	82	377672.5668
7	84	129.614814	200	1279.650093
8	110	314.6426545	900	143.9770302
9	330	372.2902094	420	841.476201
10	420	462.8174586	510	415.3252485
11	510	597.4947699	700	172.30089
12	700	700	-1	52.21452675
13				

Output Files from Code – All Other Values for Thresholds

Output files containing the event-integrated fluence for the integral or differential energy bins, as specified by user. There is a fluence file that corresponds to each threshold definition. For example, for GOES-13 spacecraft differential channels for Jan. 23, 2012 event:

sep_values_GOES-13_differential_2012_1_23.csv

	A	B	C	D	E	F	G	H	I	J
1	#Energy Threshold [MeV]	Flux Threshold [pfu]	Start Time	Peak Flux 1/[MeV cm^2 s sr]	Peak Time	Rise Time	End Time	Duration	Fluence >10 MeV [cm^-2]	Fluence >100 MeV [cm^-2]
2	>10	10	1/23/12 5:25	6740.972728	1/24/12 15:30	1 day 10:05:00	1/27/12 15:15	4 days 9:50:00	5028965341	4867346.342
3	>100	1	1/23/12 4:35	4.224547706	1/23/12 8:05	3:30:00	1/24/12 18:40	1 day 14:05:00	4254464976	3486739.932
4										

Threshold definition

Time of first threshold crossing

Peak flux between start and end times

Time of Peak

Time from start to peak

End of event

End time – start time

>10 MeV and >100 MeV event-integrated fluences integrated between the start and end times for the threshold definition in the row. Units [cm^{-2}]

Using the Code with Model Results

- **If you would like me (Katie Whitman) to fill out these values for you on the following slides, you may send me flux time profiles output from your model in a text or csv file (Kathryn.Whitman@nasa.gov).**
  - Time in YYYY-MM-DD HH:MM:SS in the first column
  - Fluxes in each additional column
  - Indicate the associated energy bins for each column
  - If prepared by Katie, all model files and results will NOT be shared and will be sent only to you so you may choose to share at SHINE
- **You may also use the code distributed with this presentation: operation_sep_quantities.py. Write to Katie for support with the code.**
- Or use your own method, but we are trying to make this as easy as possible for modelers to participate!!