Summary of the SHINE 2019 SEP Modeling Challenge Results

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SEP Modeling Challenge: Research to Operations Session Concept

- Bring together SEP modelers, observers, NASA space radiation operators, and NOAA space weather forecasters
- Inform research community of NASA SRAG and NOAA SWPC operational needs
- Show model results for operationally relevant information for 3 SEP events
- Link to session description on SHINE website: https://shinecon.org/shine2019/session2019.php#session19

Contributing Models and Speakers

Scene Setters: Phil Quinn (NASA JSC SRAG) and Hazel Bain (CU Boulder CIRES/NOAA SWPC)

Model	Author	Model Type
ENLIL+SEPMOD	Luhmann, Lee (Berkeley)	Physics-based: Time Profile
AFRL PPS and ADEPT	White, Kahler (AFRL)	Empirical: Onset, Peak Flux, Time profile
ENLIL+EPREM	Schwadron, Poduval (UNH)	Physics-based: Time Profile
STAT (MAS + EPREM)	Linker (PSI)	Physics-based: Time Profile
iPATH	Li (UAH)	Physics-based: Time Profile
SEPSTER	Richardson (U Maryland, GSFC)	Empirical: Peak Flux
UMASEP	Núñez (University of Malaga)	Empirical: Onset flux profile over 7 – 11 hours
ESPERTA	Laurenza (INAF)	Empirical: SEP Storm Class (≥S1, ≥S2)
SEP Electron Transport	Du Toit Strauss (NWU)	Physics-based, Poster

Session Focus and Discussion

- What is needed from SEP models to support human space exploration?
  - Why specific thresholds? (>10 MeV, 10 pfu and >100 MeV, 1 pfu)
  - What about the needs of lunar missions?
  - How do you handle the onset of an SEP event during an EVA?
  - What data is used to understand the biological impact of radiation?
- Need for All Clear models to predict yes/no SEP event in next 24 hours.
  - Event scarcity; validation; how to assess skill scores; probability according to needs of user
  - Suggestion that a prediction system should be flexible and interpret probabilities according to severity of event (changing ratio of FAR, POD, etc)
- Are heavy ions important?
  - Only if a case could be made that they contribute significantly to dose (AMS or PAMELA He measurements at high energies?)
- A variety of models are desired to support operational needs.
  - Probabilistic, All-Clear, deterministic, peak flux, time profile

Session Focus and Discussion

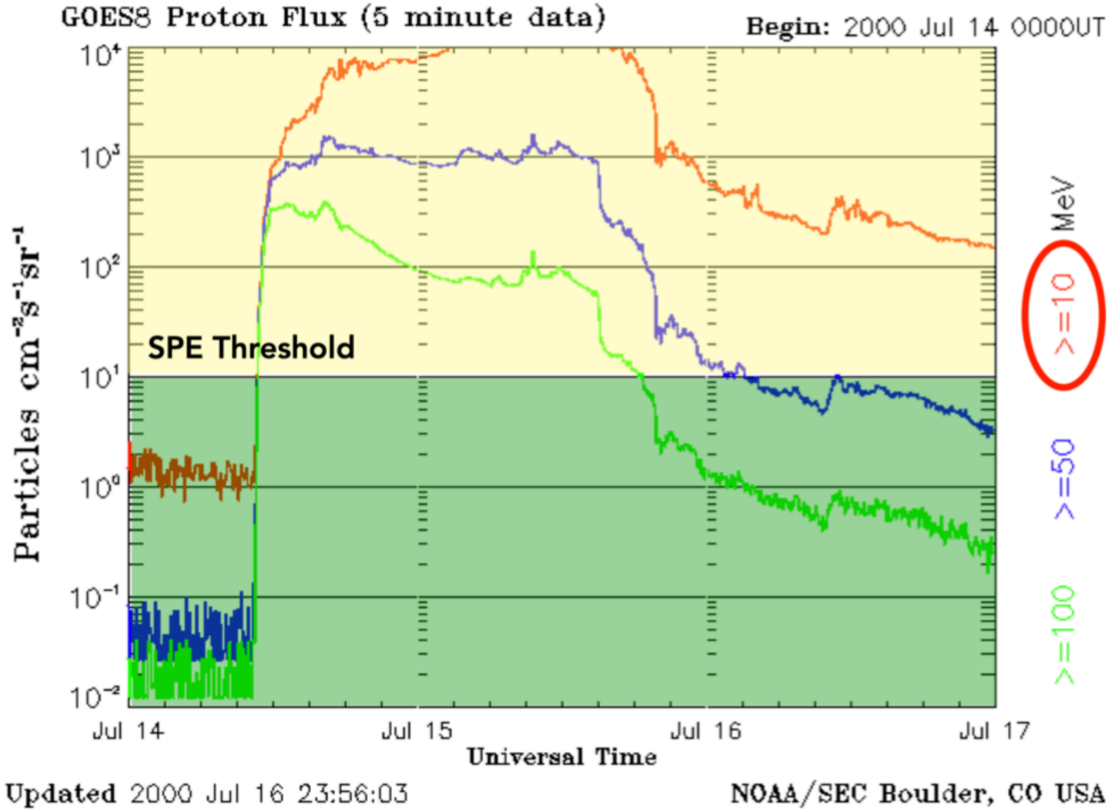
- ➢Details around determining skill of forecasters and prediction efficiency.
  - Human forecasters tend to do better around solar maximum, perhaps because many events are ongoing and 2nd, 3rd day prediction of continued increase correctly forecasted.
  - Exactly what do you count as hit or miss? How do you define an event?
  - What is meant by climatology (for skill scores)?
  - Perhaps there is a physical explanation for higher skill near solar max, e.g., more seed particles available, so a large flare/CME combo is more likely to produce SEPs
  - More important during solar max to be able to predict “No Event/All Clear”
  - When is a warning called off? Apparently there is a lot of culture that goes into that decision.
  - Bring in validation techniques from meteorology?

- ➢Currently, no operational coronagraph. Long cadence and large latency of science-focused coronagraphs causes forecasters to “fly blind” sometimes. Can be 6+ hours after CME before data arrives.
  - SWFO coming in 2024

Session Focus and Discussion

- All physics-based time profile models suffer from unknown seed population
  - Modelers basically tune this parameter to match to data
  - Gap in available data and knowledge about seed population near the Sun
  - One approach: transport 1 AU quiet-time particle spectrum down to inner boundary, then adjust intensity to match SEP observations at 1 AU
- Physics-based models that depend on ENLIL start at 20 R_{sun} from the solar corona
  - Miss acceleration of highest energy particles closer to Sun; particle onsets are late
- Physics-based modelers tend to choose single magnetic field lines to get SEP flux prediction
  - Is there a better way to do this? Interpolation? Clusters?
  - Perhaps look to the meteorology community, which deals with 2D, 3D distributions
- Debate about using Parker Spiral for transport
- Modelers shared predictions and ongoing/future work

Operational Thresholds and Actions for Crew Safety During EVAs



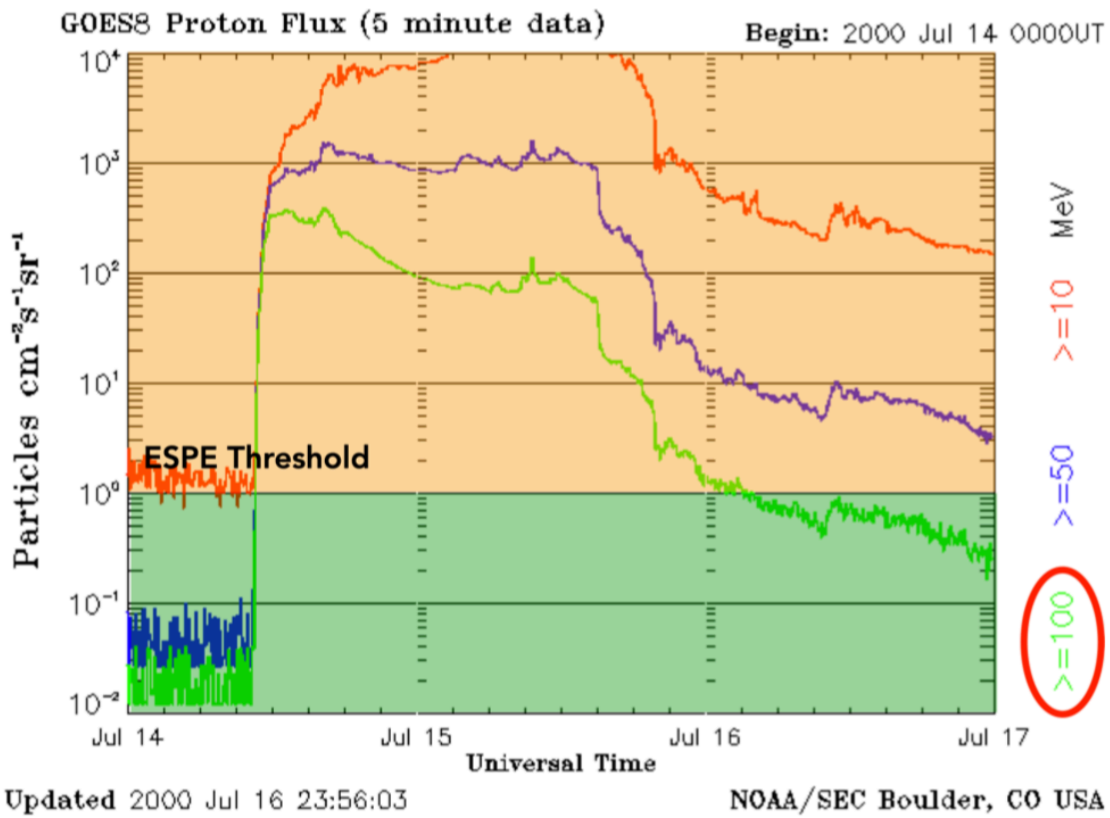
Solar Proton Event (SPE)

- Defined by GOES measurements when $\geq$ 10 MeV protons $\geq$ 10 pfu.
- Important during EVAs where crew is outside of spacecraft shielding.
- SRAG console operator predicts dose based on GOES proton flux and spacecraft location then gives a recommendation to Surgeon.

Condition	Upcoming EVA	EVA in Progress
Predicted Dose < Action Level	Delay up to 2 days	Continue but do not add tasks
Predicted Dose > Action Level	Delay up to 14 days	Continue and expedite tasks
Predicted Dose Rate > High Dose Rate Limits	Reschedule	Expedite by deleting tasks
Predicted Dose > Joint Exposure Limits	Reschedule	Terminate

Courtesy: Phil Quinn (NASA JSC SRAG)

Operational Thresholds and Actions for Crew Safety During IVAs



Energetic Solar Proton Event (ESPE)

- Defined by GOES measurements when $\geq$ 100 MeV protons $\geq$ 1 pfu.
- Important during IVAs since higher energy protons can penetrate the lower shielded areas of the spacecraft.
- If threshold is crossed, SRAG console operator alerts the FCT.
- SRAG console operators remains on console for the entire event duration.

Condition	Action
$\geq$ 100 MeV protons $\geq$ 1 pfu	Inform crew to avoid lower shielded areas
$\geq$ 100 MeV protons $\geq$ 100 pfu	Inform crew to stay in higher shielded areas

Courtesy: Phil Quinn (NASA JSC SRAG)

Future SEP Forecasting Requirements

Courtesy: Hazel Bain (CU Boulder CIRES/ NOAA SWPC)

When?

Increase forecast lead time. Particularly for prompt events.

How big?

Improved forecasts of peak intensity.

> 10 MeV

> 100 MeV

> 500 MeV

Forecast issued 30 mins – 3 hrs after onset

How long?

Event duration

Time Intensity profiles

Low False Alarm Rate

SEP Quantities Requested for this Modeling Challenge

- **Two important thresholds**
  - >10 MeV proton fluxes exceed 10 pfu (1/[cm^2 s sr])
  - >100 MeV proton fluxes exceed 1 pfu ← most important to SRAG

- **Operational quantities of interest**
  - Will thresholds be exceeded in the next 24 or 48 hours? Probabilistic, All-Clear
  - When will these thresholds be crossed? Event start time
  - How strong will the event be? Peak flux, fluence
  - How quickly must astronauts act to mitigate radiation dose? Rise time (start time to time of peak)
  - How long will the event last? End time, duration

- **Multiple model types would be very useful in an operational setting!**

For Modelers: Data Preparation Package for SHINE 2019

- Kathryn Whitman developed a series of codes to help modelers calculate the values requested for the SHINE 2019 SEP Modeling Challenge session

➢ GitHub repository: https://github.com/ktindiana/operational-sep

- **Code: operational_SEP_SHINE_wrapper.py**
  - Runs operational_sep_quantities.py for all SHINE events for all combinations of GOES-13, GOES-13, and SEPEM data types
  - Allows users to specify model info and runs operational_sep_quantities.py for model
  - Makes comparison plots with compare_data_model.py and saves to file
- **Code: operational_sep_quantities.py**
  - Calculates all values requested for shine session for GOES and SEPEM measurements (https://shinecon.org/shine2019/session2019.php#session19)
  - **Can calculate the same values for any model that outputs integral or differential flux time series**
- **Code: compare_data_model.py**
  - Make comparison plots between measurements and model results

Overview of Models

Alphabetical order

Model: AFRL PPS

Developers: Peggy Shea and Don Smart (Stephen Kahler, Stephen White)
Model Type: Empirical, deterministic
Quantities Predicted: >10, >50 MeV proton peak flux, rise time, simple time profile

TABLE I.1 ALGORITHMS FOR CONVERTING SEMI-INTEGRATED RADIO FLUX DATA (F_S) TO PEAK PROTON FLUX (J)

FREQUENCY (MHz)	ALGORITHM
1415	$J(>5.2) = \frac{1}{C}(2.97 \times 10^4\ F_{SW}{}^{0.243})^2$
2695	$J(>5.2) = \frac{1}{C}(8.63 \times 10^8\ F_{SW}{}^{0.513})^2$
4995	$J(>5.2) = \frac{1}{C}(5.97 \times 10^7\ F_{SW}{}^{0.453})^2$
8800	$J(>5.2) = \frac{1}{C}(9.12 \times 10^6\ F_{SW}{}^{0.406})^2$

TABLE I.2 ALGORITHMS FOR CONVERTING EVENT INTEGRATED RADIO FLUX DATA (F_I) TO PEAK PROTON FLUX (J)

FREQUENCY (MHz)	ALGORITHM
1415	$J(>5.2) = \frac{1}{C}(1.74 \times 10^6\ F_{IW}{}^{0.376})^2$
2695	$J(>5.2) = \frac{1}{C}(1.66 \times 10^6\ F_{IW}{}^{0.380})^2$
4995	$J(>5.2) = \frac{1}{C}(4.57 \times 10^5\ F_{IW}{}^{0.352})^2$
8800	$J(>10) = 3.4 \times 10^{24}\ F_{IJ}{}^{1.43}$
2800	$J(>5.2) = \frac{1}{C}(0.0116\ F_{IS}{}^{0.555})^2$

TABLE I.3 ALGORITHMS FOR CONVERTING INTEGRATED X-RAY FLUX (F_X) TO PEAK PROTON FLUX (J)

SENSOR WAVELENGTH RANGE (ANGSTROMS)	ALGORITHM
1–8	$J(>10) = 2.222 \times 10^3\ F_{XW}{}^2$
0.5–4	$J(>10) = 5.555 \times 10^4\ F_{XW}{}^2$

NOTES: 1 SFU $= 10^{-22}$ $Wm^{-2}\ Hz^{-1}$
1 JOULE = WATT SEC.

F_{SW} DESIGNATES UNITS FOR SEMI-INTEGRATED RADIO DATA AND MUST BE $(Wm^{-2}\ Hz^{-1})$ SEC.

F_{IW} DESIGNATES UNITS FOR EVENT INTEGRATED RADIO DATA AND MUST BE $(Wm^{-2}\ Hz^{-1})$ SEC.

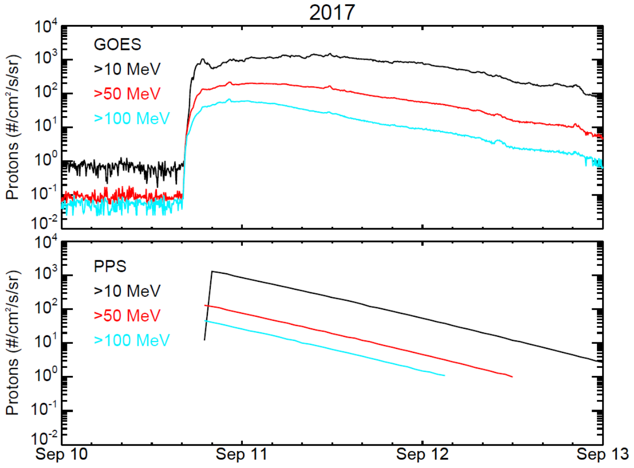
F_{IJ} DESIGNATES UNITS FOR EVENT INTEGRATED RADIO DATA AND AND MUST BE $Jm^{-2}\ Hz^{-1}$

F_{IS} DESIGNATES UNITS FOR EVENT INTEGRATED RADIO DATA AND MUST BE SFU SEC.

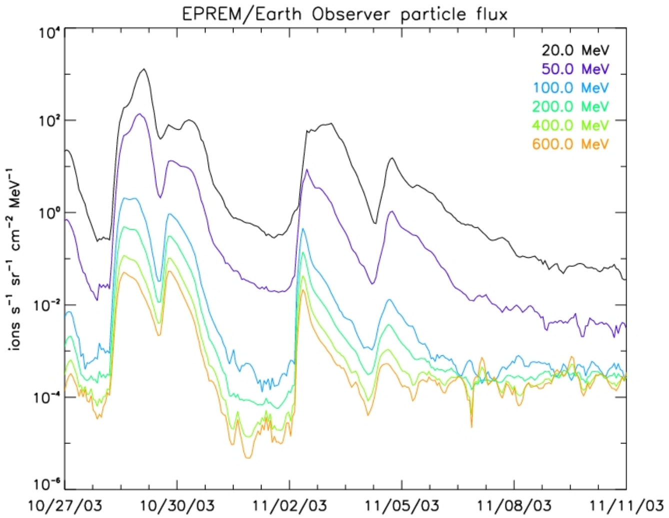
F_{XW} DESIGNATES UNITS FOR X-RAY DATA IN UNITS OF Wm^{-2} SEC.

C IS A CONVERSION FACTOR RIOMETER ABSORPTION SQUARED TO >5.2 MeV PROTON FLUX DATA. $C = (0.115)^2 \pi$

Model Summary: Based off of Smart & Shea (1979, Proc. Solar Terr. Predictions). Determine a predicted maximum intensity based on radio flux or fluence or SXR fluence, modify the prediction with additional parameters, such as position, etc.



Model: EPREM (Energetic Particle Radiation Environment Model)

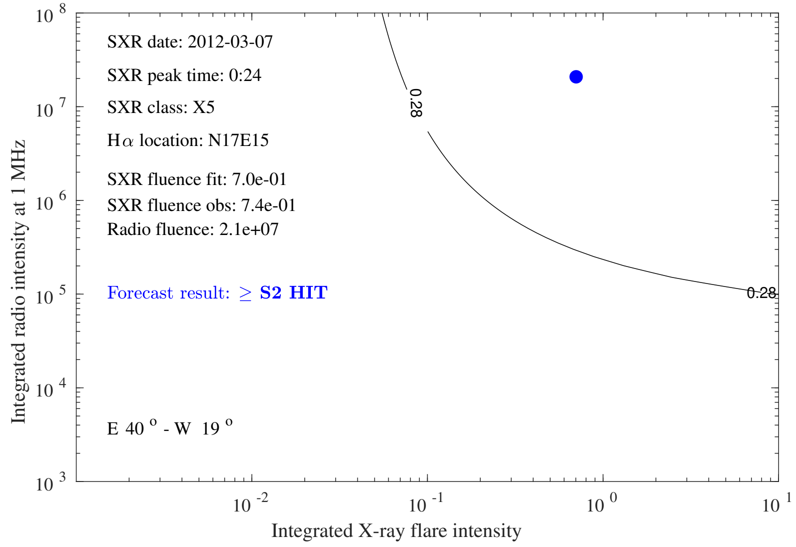


Developers: Schwadron, Gorby et al.
Model Type: Physics-based, deterministic
Quantities Predicted: Time profile of SEP protons over a broad energy range.

Model Summary: EPREM is a 3D kinetic model that simulates particle transport anywhere in the heliosphere. It uses a Lagrangian grid scheme, *i.e.* the nodes where information is stored move with the plasma. It solves the Focused Transport Equation and includes terms for convection, parallel diffusion, adiabatic focusing, adiabatic cooling, and pitch-angle scattering. There is a separate module within EPREM that solves for perpendicular diffusion and particle drift.

Notes: EPREM may be coupled with any MHD code and is currently being run with ENLIL and MAS (as a part of the STAT model from PSI and UNH).

Model: ESPERTA (Empirical model for Solar Proton Event Real Time Alert)

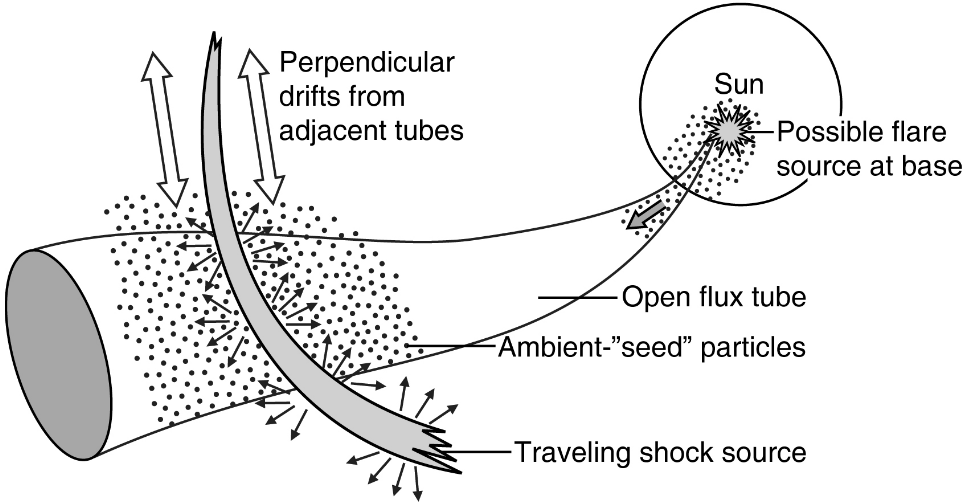


Developers: Laurenza et al.
Model Type: Empirical, categorical
Quantities Predicted: Whether an event will be ≥S1 or ≥S2

Model Summary: ESPERTA generates a prediction based on flare location, flare size, and evidence of particle acceleration/escape as parameterized by flare longitude, time-integrated soft X-ray intensity, time-integrated intensity of type III radio emission at ~1 MHz.

Notes:
For ≥S1 events: Probability of Detection (POD) of 63% for 1995 – 2014, False alarm rate (FAR) of 38% , Median (minimum) warning time of ~4.8 (0.4) hr
For ≥S2 events: POD of 75% (41/55) for 1995 – 2014, FAR of 24% (13/54)

Model: SEPMOD



Developers: Luhmann et al.
Model Type: Physics-based, deterministic
Quantities Predicted: Time profile of SEP protons over a broad energy range, including a >500 MeV integral flux prediction, with pitch angle distribution (anisotropy) information.

Model Summary: SEPMOD is a test particle code that assumes that SEP particles are accelerated at the shock created by an ICME as it propagates outwards from the sun. The shock information and ambient solar wind structure are derived from an MHD model. SEPMOD tracks the magnetic connectivity from the shock front to the observer and transports particles along the connected field lines. The model runs shown below use the ENLIL solar wind model which starts at 21.5 Rs.

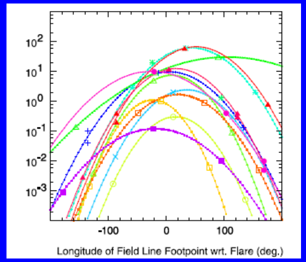
Notes: SEPMOD includes ESP effects and an option to add flare SEPs with fixed Sun source. Mirroring is included in particle transport, but not scattering or drifts.

Model: SEPSTER (Solar Energetic Particle prediction based on STEReo)

Developers: Ian Richardson
Model Type: empirical, deterministic
Quantities Predicted: Peak time; 14 – 24 MeV proton peak flux; >10, >30, >50, >100 MeV proton peak flux

SEP Proton Intensity Prediction Formula (*Richardson et al.*, 2014)

14-24 MeV Proton Intensity Gaussian fit vs. φ for 3 spacecraft (STEREOs + near Earth) events



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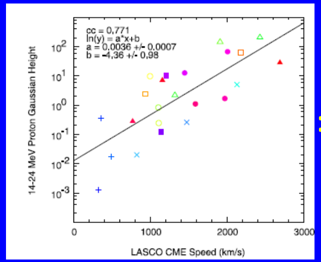
Gaussian peak intensity vs. CME speed (CDAW)



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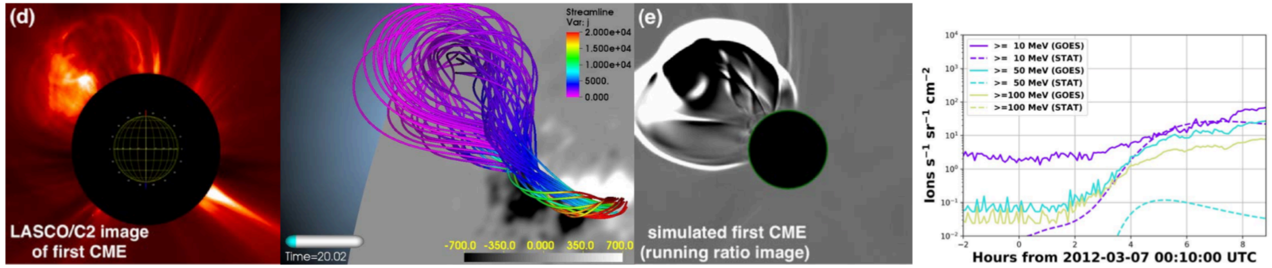
$I(\varphi)$ (MeV s cm^2 sr)$^{-1}$ ≈ 0.013 exp($0.0036V - \varphi^2/2\sigma^2$)), σ = 43°, where:

φ is the connection angle (longitude) between the solar event and the solar footpoint of the spiral magnetic field line passing the observing spacecraft, and
σ is the Gaussian width; 43° is the average value.

Model Summary: SEPSTER is triggered by a report of a CME and gives the peak intensity and estimated peak time of 14-24 MeV protons. The peak proton intensities of other energies are extrapolated. Predictions are made based on an equation that relates the intensity of SEPs at 14-24 MeV to the speed of a CME and the "connection angle" between the CME direction and the footpoint of the field line passing the observer.

Notes: Estimates of the intensity or integrated flux in other proton energy ranges are made using the typical ratios of the values based on correlating the intensities in a sample of SPEs. For GOES >10, >30, >50, and >100 MeV proton flux, the scaling values are $\sim 20I_p$, $\sim 2I_p$, $\sim I_p$, $\sim 0.2I_p$, respectively, where I_p is the intensity predicted for 14 – 24 MeV protons.

March 7, 2012 Event



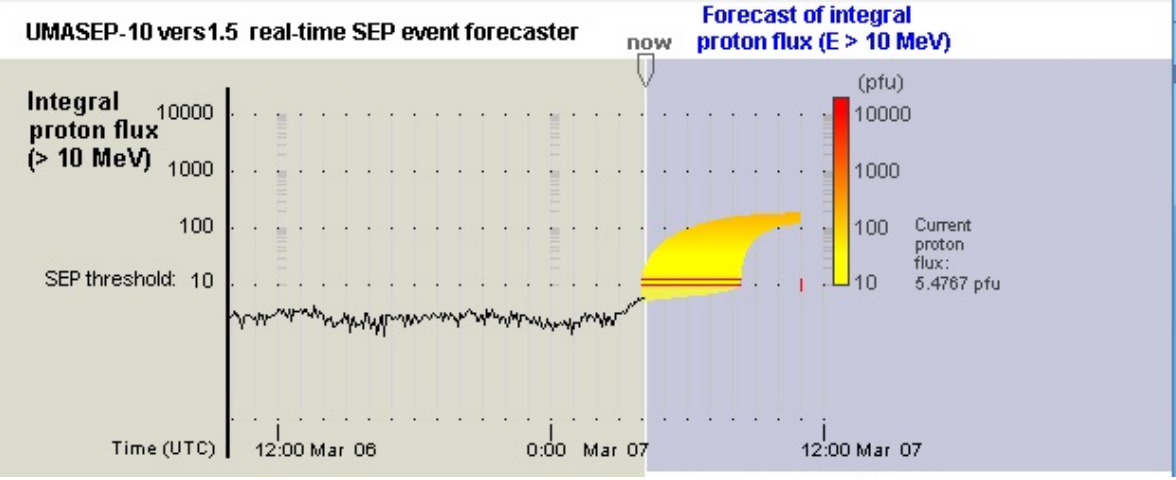
Model: STAT (SPE Threat Assessment Tool)

Developers: Linker (PSI), Schwadron (UNH) et al.
Model Type: Physics-based, deterministic
Quantities Predicted: Fully 3D, time-dependent simulation of protons in the heliosphere from the corona to 1 AU.

Model Summary: STAT is composed of two models: CORona-HELiosphere (CORHEL) / Magneto-hydrodynamic Algorithm outside a Sphere (MAS) model and EPREM. MAS provides the fully 3D, time-dependent MHD solution of the eruption and propagation of a CME in the solar wind. EPREM performs the 3D transport of protons out to 1 AU.

Notes: The MAS outer boundary is located around $30R_{sun}$, therefore the STAT simulation duration is limited to the amount of time it takes for the CME to propagate beyond this boundary. STAT captures the initial onset and rise of an SEP event, but does not currently produce a complete SEP time profile. If MAS is linked to a solar wind simulation extending beyond $30R_{sun}$, STAT can continue propagation of the CME and produce full SEP time profiles. This type of improvement will be implemented into later versions of STAT.

Model: UMASEP



Developers: Marlon Nuñez
Model Type: empirical, deterministic
Quantities Predicted: Maximum possible flux (with uncertainty) within 7 hours after the flux threshold is crossed for >10 MeV and >100 MeV integral fluxes.

Model Summary: UMASEP is a family of models – UMASEP-10, UMASEP-100, and UMASEP-500, which make predictions for >10 MeV, >100 MeV protons and the occurrence of GLEs, respectively. UMASEP applies empirical relationships between X-ray measurements and proton fluxes. UMASEP-10 considers whether an event may be well-connected or poorly-connected.

Notes: UMASEP predicts that a threshold will be crossed within 2 hours of the forecast time. A possible SEP time profile is generated by interpolating between the projected maximum flux (including error bars) back down to the 2 hour threshold-crossing window. UMASEP makes a new prediction every few minutes and aggregates the max flux predictions and profile bands on its output plot. The highest density of predicted values should be considered the most likely outcome.

Model Forecast Summary

Model	Start Time		Peak Time (Rise Time)		End Time (Duration)		Peak Flux		Fluence	
	>10 MeV	>100 MeV	>10 MeV	>100 MeV	>10 MeV	>100 MeV	>10 MeV	>100 MeV	>10 MeV	>100 MeV
AFRL PPS	✓		✓		✓		✓			
EPREM	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ESPERTA							✓			
SEPMOD	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SEPSTER			✓				✓	✓		
STAT[1]	✓	✓		✓				✓		
UMASEP[2]	✓	✓	✓	✓						

[1]Current STAT predictions are only valid for a few hours, thus it can predict high energy peak flux and peak time for very prompt events (peak within ~7 - 8 hours).

[2]UMASEP predicts flux at a certain time after an event begins, thus it can predict peak flux for very prompt events (peak within ~7 - 8 hours).

Model Forecast Comparison with Data

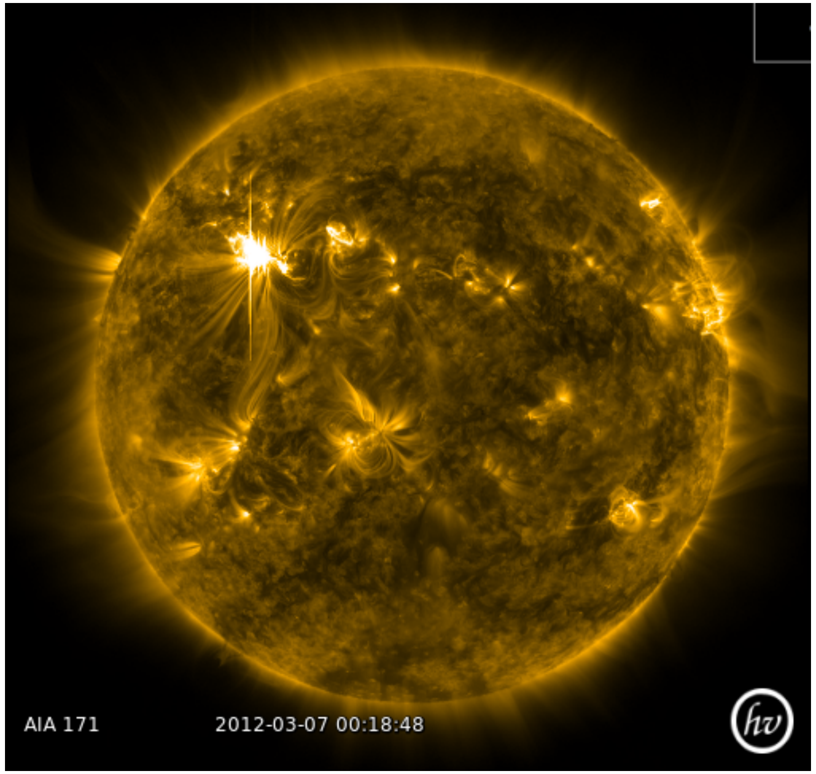
Note about the definition for the peak of an SEP event. Especially in the >10 MeV, two peaks could be considered: 1) peak due to the initial acceleration and onset of the particles; 2) the peak of the energetic storm particle (ESP) event due to the passing CME.

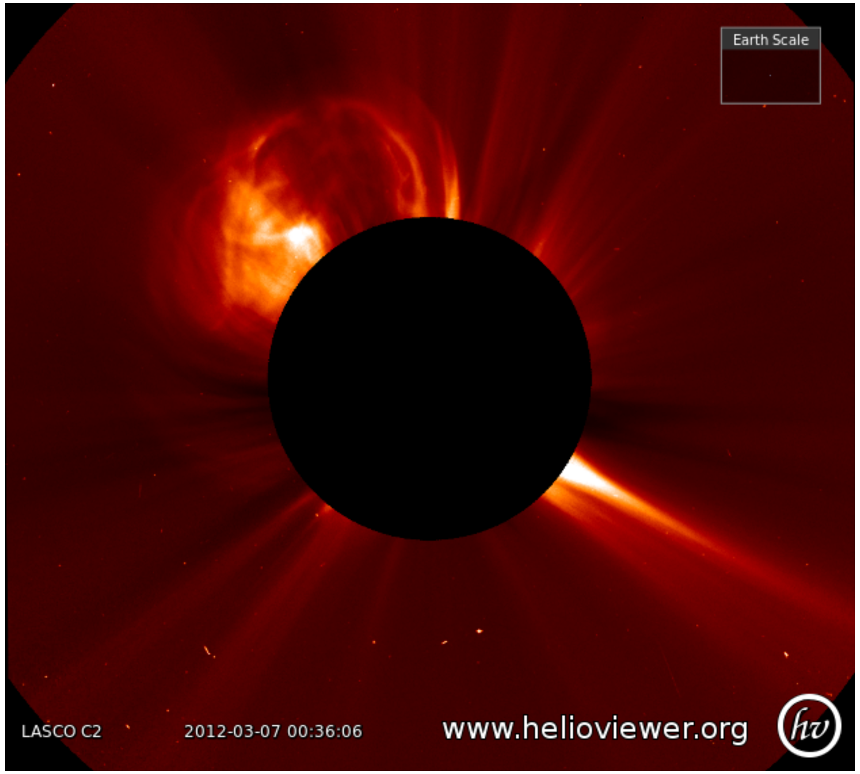
No effort has been taken to differentiate between these two types of peaks in this comparison. The peak flux is defined as the highest flux value between the start and end times.

Predictions from AFRL PPS, ESPERTA, SEPSTER, STAT, UMASEP

March 7, 2012

March 7, 2012 SEP Event



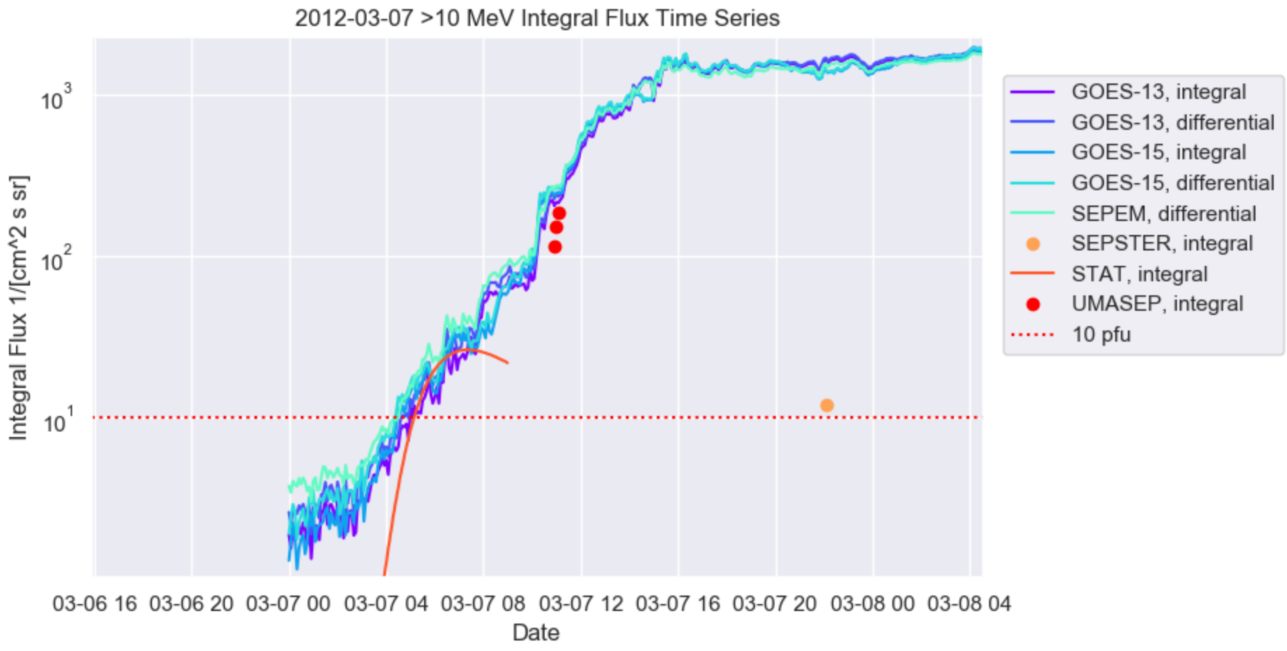


Flare Class	Start	Peak	End	NOAA AR	LAT	LON
X5.4	00:02	00:24	00:40	11429	N18	E31

CME Speed (km/s)	CME Width	First Appearance Time (LASCO C2)
2684	Halo	00:24:06

Forecast: SEP Onset for >10 MeV protons
March 7, 2012 (>10 MeV exceeds 10 pfu)

Onset Time Profile



STAT performs well in the first few hours of simulation prior to the CME approaching the MAS $30R_{sun}$ outer domain.
UMASEP predicts a flux (the range of uncertainty is indicated by the upper and lower dots) close to the measured values during onset.

Start Time

Operational Satellite: GOES-13, >10 MeV channel
Start Time: 2012-03-07 05:00:00

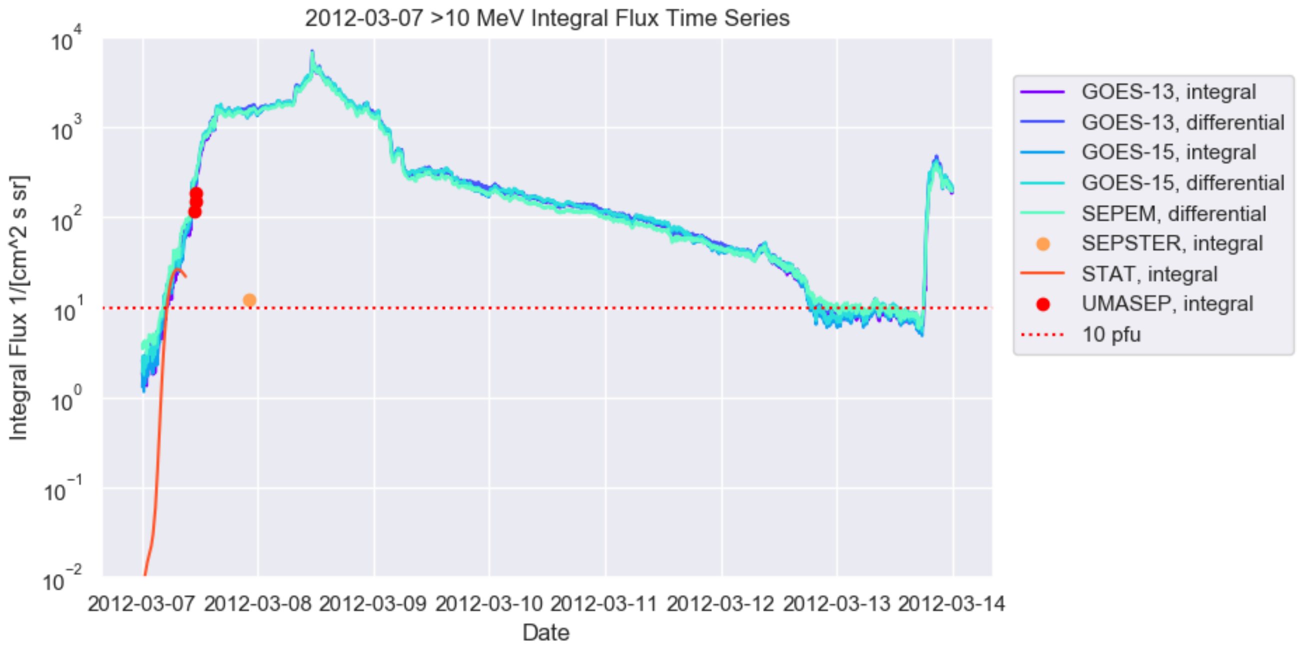
Model Predictions

Early/Low | Similar to Data | Late/High

Model	Start Time	Difference
STAT	05:13:00	+13 minutes
UMASEP	04:00 – 08:20	-60, +220 min

Forecast: SEP Time Profile for >10 MeV protons
March 7, 2012 (>10 MeV exceeds 10 pfu)

Full Time Profile



SEPSTER peak time is more likely associated with the onset peak of 14 – 24 MeV and not the ESP peak. It is likely that the 14 – 24 MeV peak time is a good proxy for the >10 MeV peak time. Note that SEPSTER here uses DONKI CME parameters, and the CME direction (E60) is inconsistent with the E30 solar event location.

End Time and Duration

Operational Satellite: GOES-13, >10 MeV channel
End Time: 2012-03-12 22:55:00
Duration: 137.92 hours (5 days, 17 hrs, 55 mins)

Model Predictions

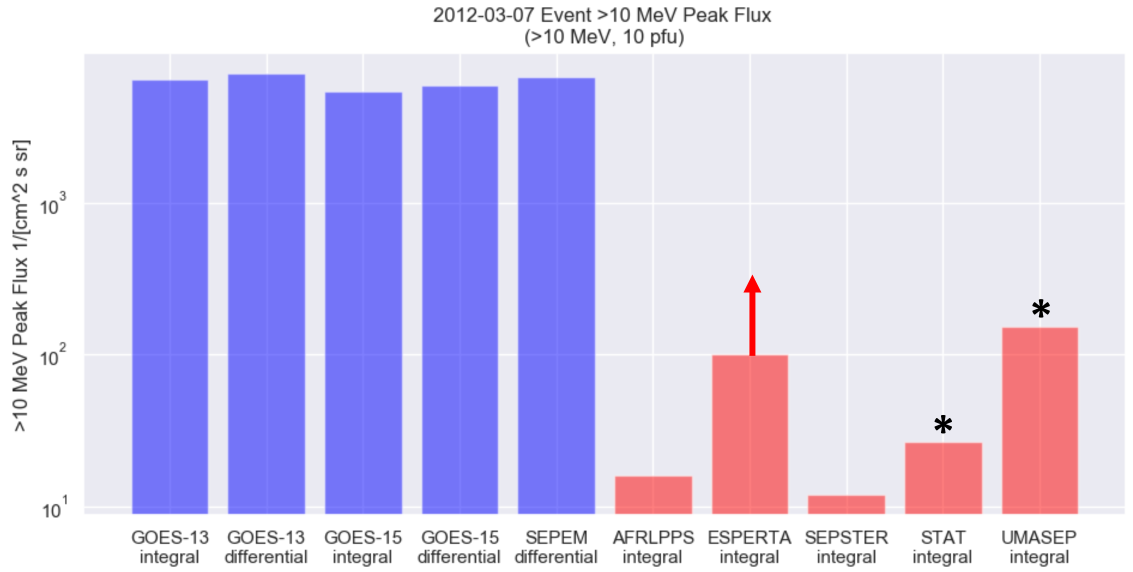
Early/Low Similar to Data Late/High

Model	End Time	Difference
	None submitted	

Model	Duration	Difference
AFRL PPS	11 hours	-126.92

Forecast: SEP Peak Flux for >10 MeV protons
March 7, 2012 (>10 MeV exceeds 10 pfu)

Peak Flux



AFRL PPS and SEPSTER underpredict this event.
ESPERTA accurately predicts that the event exceeds S2 (>100 pfu).
*STAT and UMASEP results pertain to the start of this gradual event, so are understandably lower.
✯SEPSTER peak time is more likely associated with the onset peak of 14 – 24 MeV and not the ESP peak. In this analysis, no effort was taken to differentiate between the two.

Peak Time and Rise Time

Operational Satellite: GOES-13, >10 MeV channel
Time of Peak: **2012-03-08 11:15:00**
Rise Time: **30.25 hours (1 day, 6 hrs, 15 mins)**

Model Predictions

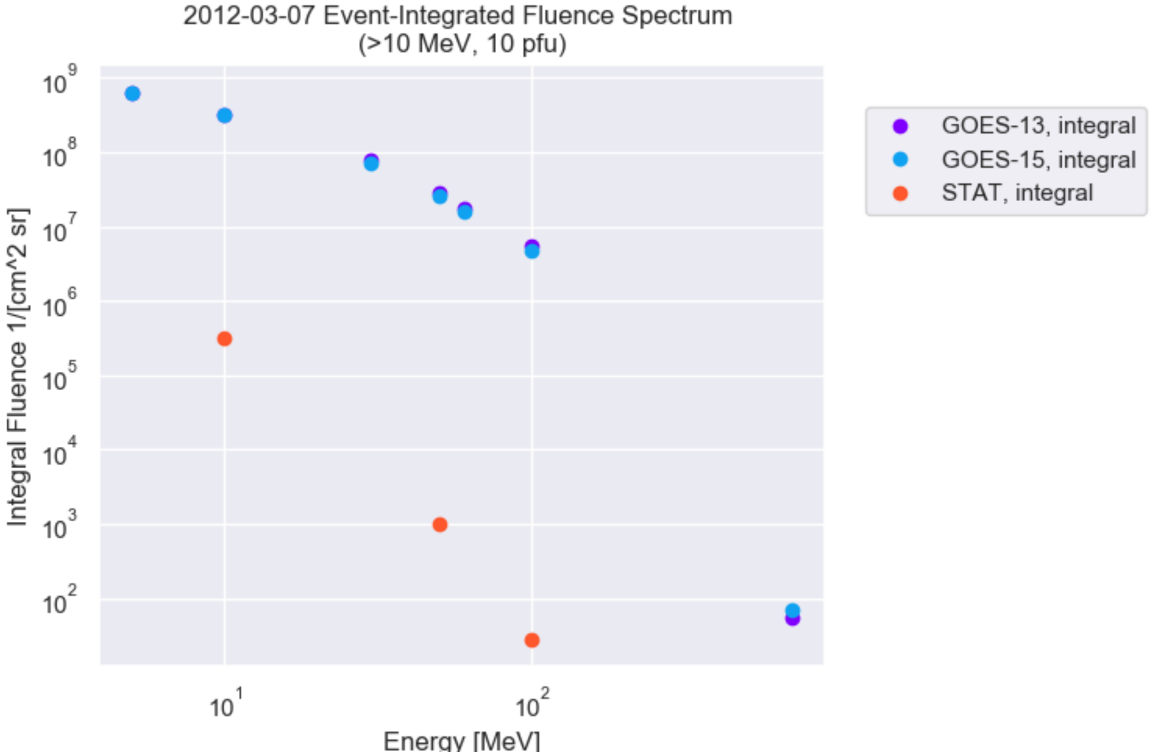
Early/Low | Similar to Data | Late/High

Model	Peak Time	Difference
SEPSTER	2012-03-07 22:05:00✯	-13.17 hours

Model	Rise Time	Difference
AFRL PPS	16 hours	-14.25 hours

Forecast: SEP Fluence for >10 MeV protons
March 7, 2012 (>10 MeV exceeds 10 pfu)

Event-Integrated Fluence



>10 MeV Event-Integrated Fluence

Operational Satellite: GOES-13, >10 MeV channel
>10 MeV Fluence: 4.08e9 cm^{-2}

Model Predictions

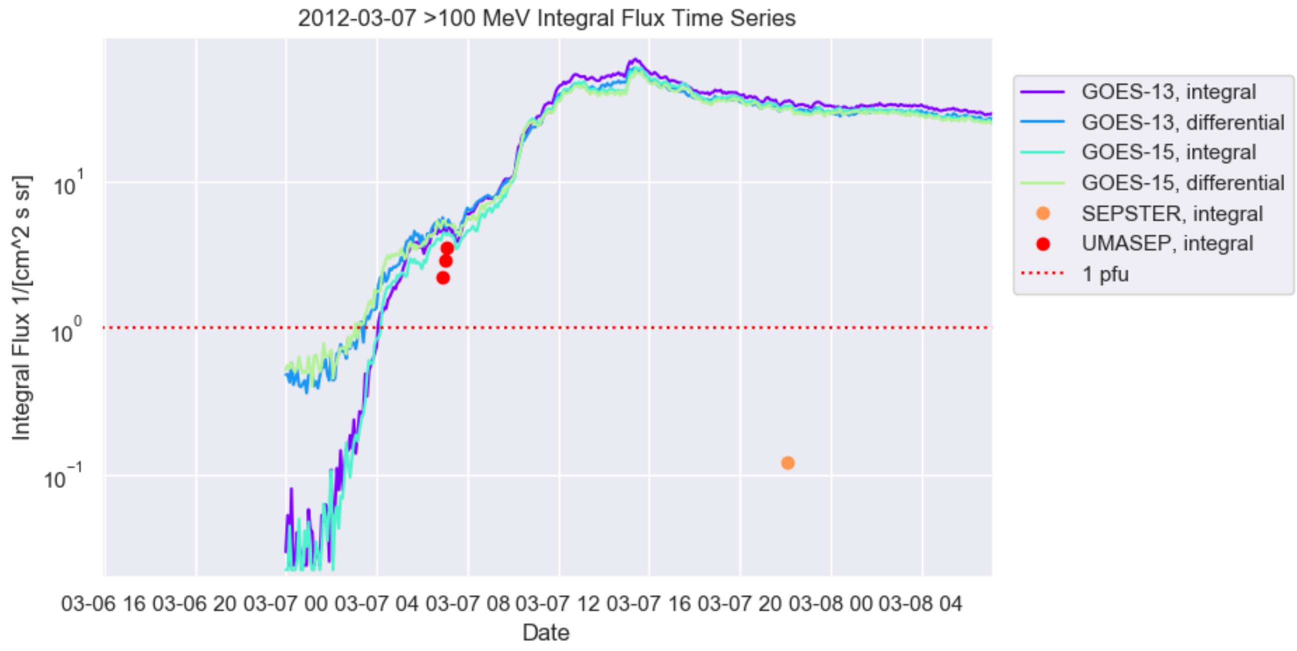
Early/Low | Similar to Data | Late/High

Model	>10 MeV Fluence	Difference
STAT*	3.93e6 cm^{-2}	-99.9%

*STAT results pertain to the first few hours of this gradual event, so the predicted fluences are lower.

Forecast: SEP Onset for >100 MeV protons
March 7, 2012 (>100 MeV exceeds 1 pfu)

Onset Time Profile



STAT predicted that >100 MeV flux would not exceed threshold.
UMASEP predicts a flux range close to the measured values during onset.
Note that the SEPSTER peak time in this plot is more pertinent to the >10 MeV channel, but is used here as an estimate.

Start Time

Operational Satellite: GOES-13, >100 MeV channel
Start Time: **2012-03-07 04:05:00**

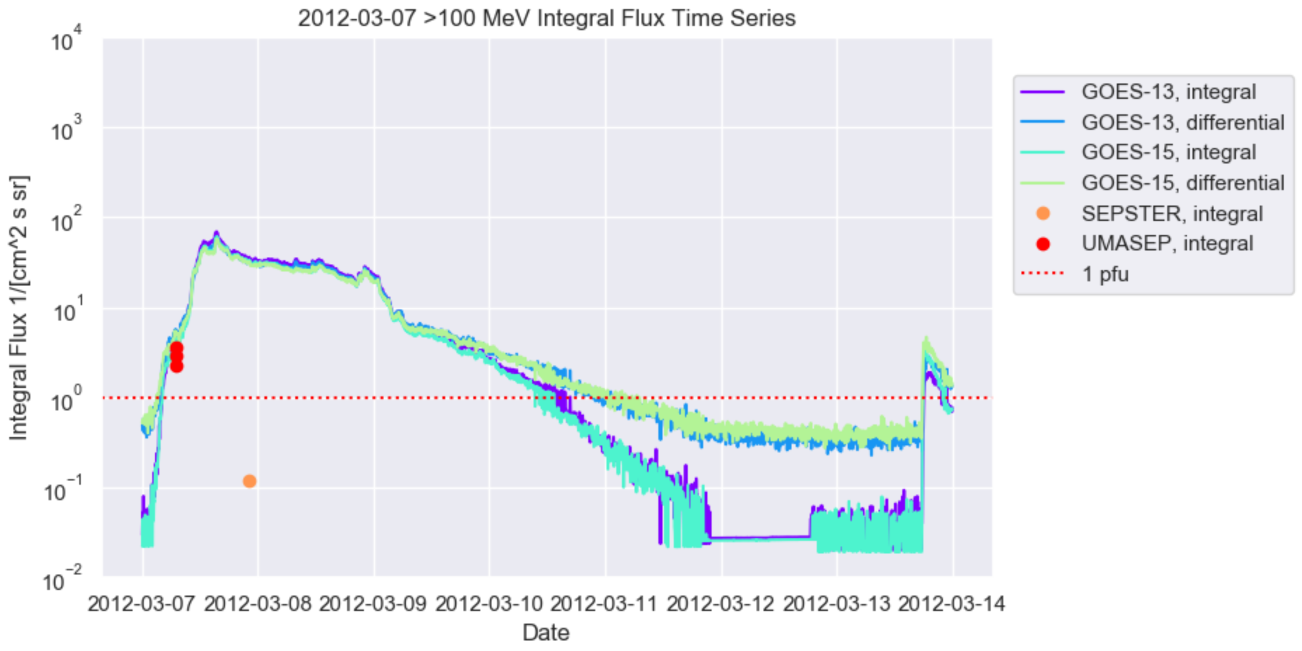
Model Predictions

Early/Low Similar to Data Late/High

Model	Start Time	Difference
STAT	-	MISS
UMASEP	04:00 - 07:00	-5, +175 min

Forecast: SEP Time Profile for >100 MeV protons
March 7, 2012 (>100 MeV exceeds 1 pfu)

Full Time Profile



Note that the SEPSTER peak time in this plot is more pertinent to the >10 MeV channel, but is used here as a broad estimate.

End Time and Duration

Operational Satellite: GOES-13, >100 MeV channel
End Time: 2012-03-10 14:30:00
Duration: 82.42 hours (3 days, 10 hrs, 25 mins)

Model Predictions

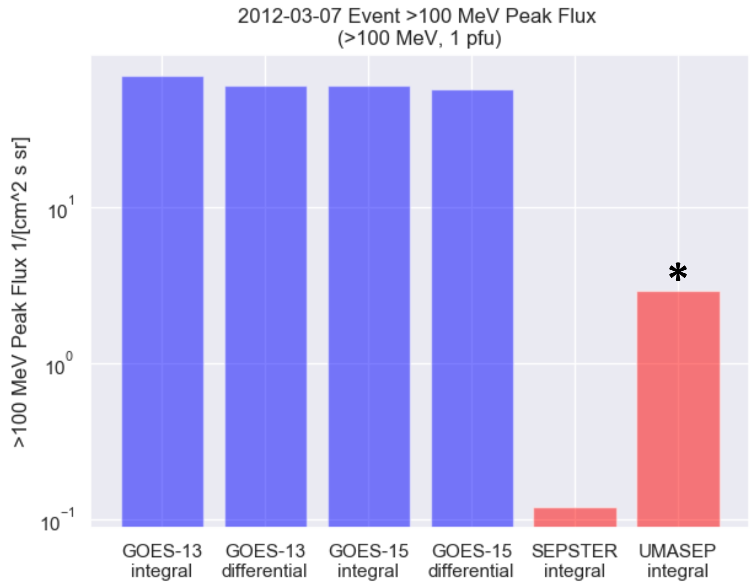
Early/Low | Similar to Data | Late/High

Model	End Time	Difference
	None submitted	

Model	Duration	Difference
	None submitted	

Forecast: SEP Peak Flux for >100 MeV protons
March 7, 2012 (>100 MeV exceeds 1 pfu)

Peak Flux



SEPSTER under-predicts this event.
*UMASEP predictions pertain to the start of this gradual event, so are understandably lower.
✯SEPSTER peak time is more associated with the onset peak of 14 – 24 MeV energies. It is included here out of interest.

Peak Time and Rise Time

Operational Satellite: GOES-13, >100 MeV channel
Time of Peak: 2012-03-07 15:25:00
Rise Time: 11.33 hours (11 hrs 20 mins)

Model Predictions

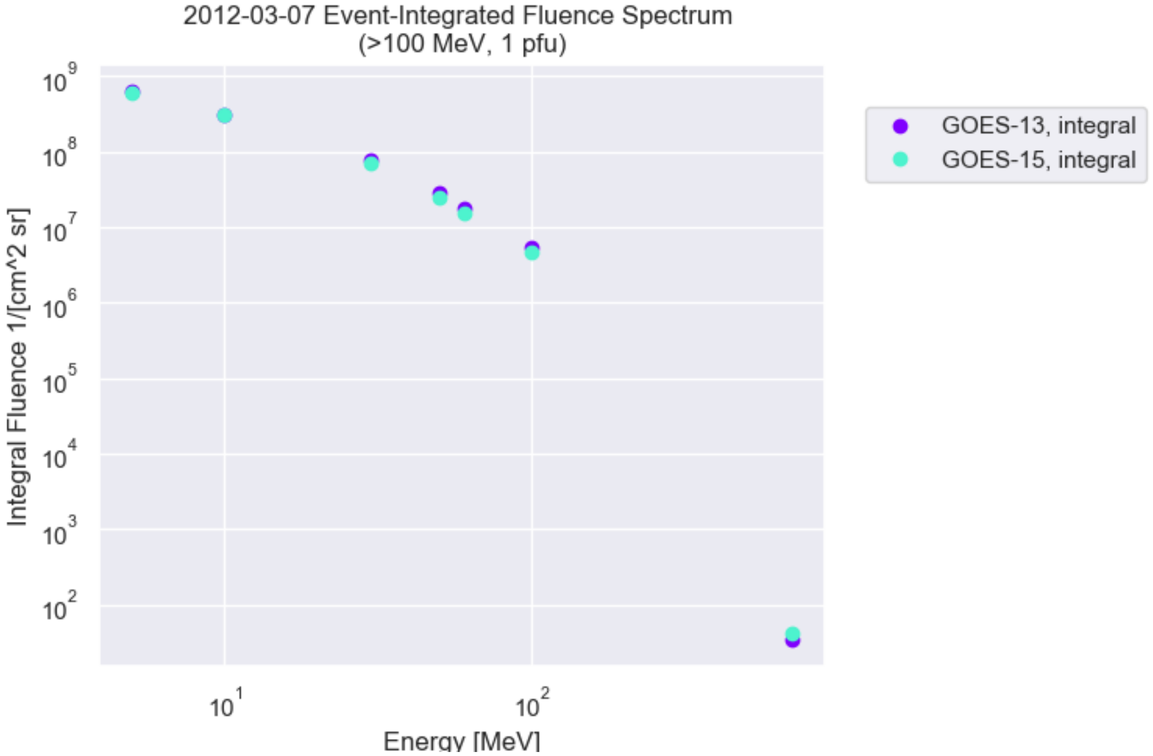
Early/Low | Similar to Data | Late/High

Model	Peak Time	Difference
SEPSTER	2012-03-07 22:05:00✯	+6.67 hours

Model	Rise Time	Difference
	None submitted	

Forecast: SEP Fluence for >100 MeV protons
March 7, 2012 (>100 MeV exceeds 1 pfu)

Event-Integrated Fluence



STAT did not predict a threshold crossing for the >100 MeV channel and thus no predicted event-integrated fluence.

>100 MeV Event-Integrated Fluence

Operational Satellite: GOES-13, >100 MeV channel
>100 MeV Fluence: 6.77e7 cm^{-2}

Model Predictions

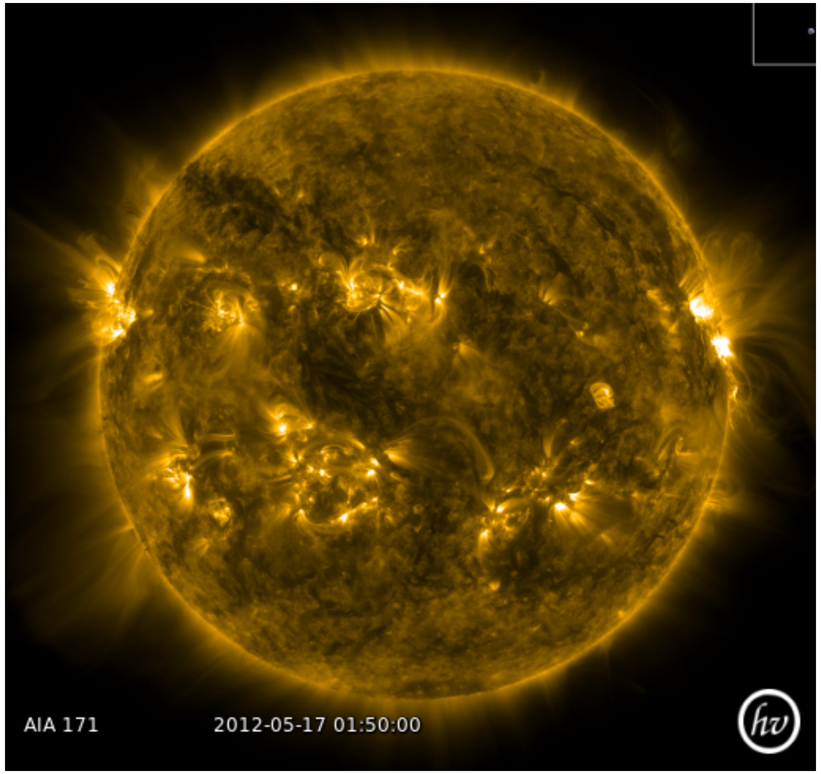
Early/Low | Similar to Data | Late/High

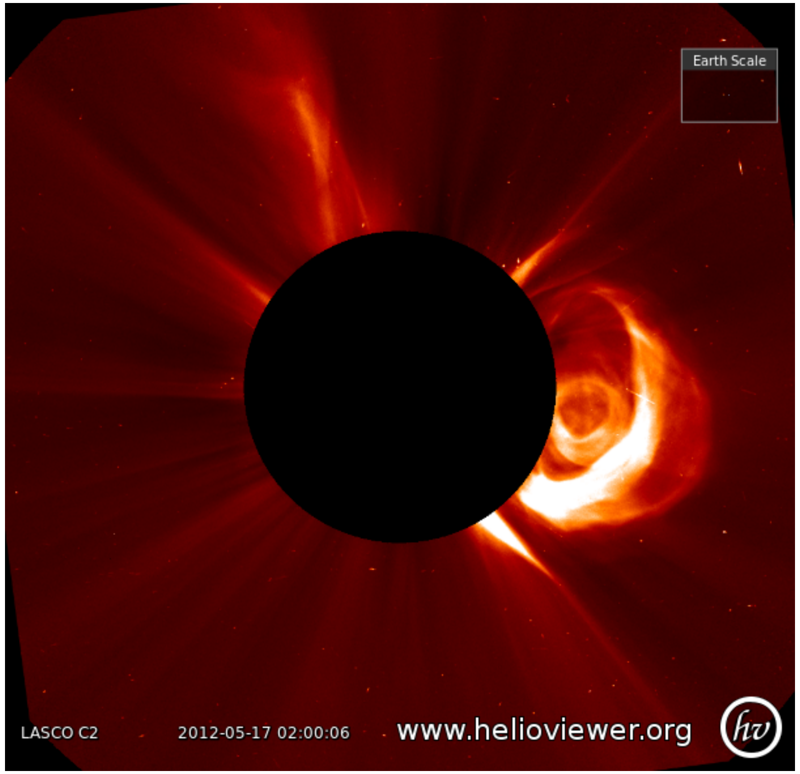
Model	>100 MeV Fluence	Difference
STAT	-	**MISS**

Predictions from AFRL PPS, ESPERTA, SEPMOD, SEPSTER, UMASEP

May 17, 2012

May 17, 2012 SEP Event



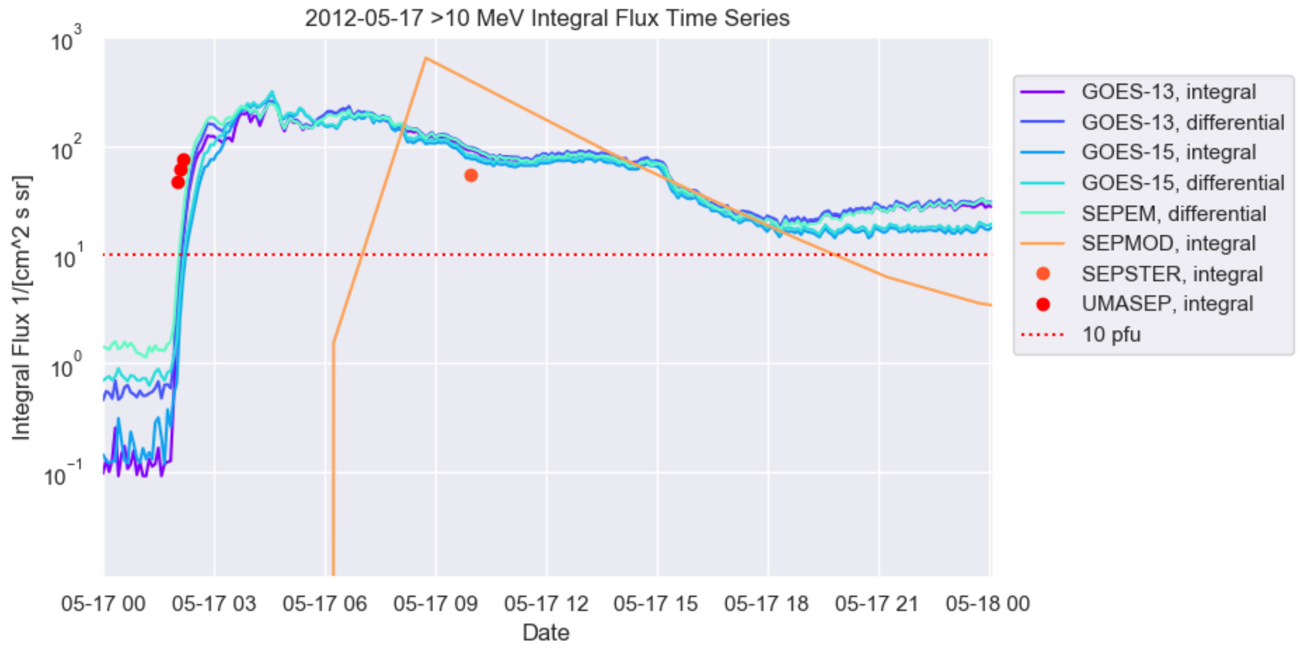


Flare Class	Start	Peak	End	NOAA AR	LAT	LON
M5.1	01:25	01:47	02:14	11476	N06	W90

CME Speed (km/s)	CME Width	First Appearance Time (LASCO C2)
1582	Halo	01:48:05

Forecast: SEP Onset for >10 MeV protons
May 17, 2012 (>10 MeV exceeds 10 pfu)

Onset Time Profile



SEPMOD uses a 2.5 hour time resolution, which likely increases the delay in start time. UMASEP predicts a flux (the range of uncertainty is indicated by the upper and lower dots) close to the measured values during onset.

Start Time

Operational Satellite: GOES-13, >10 MeV channel
Start Time: **2012-05-17 02:10:00**

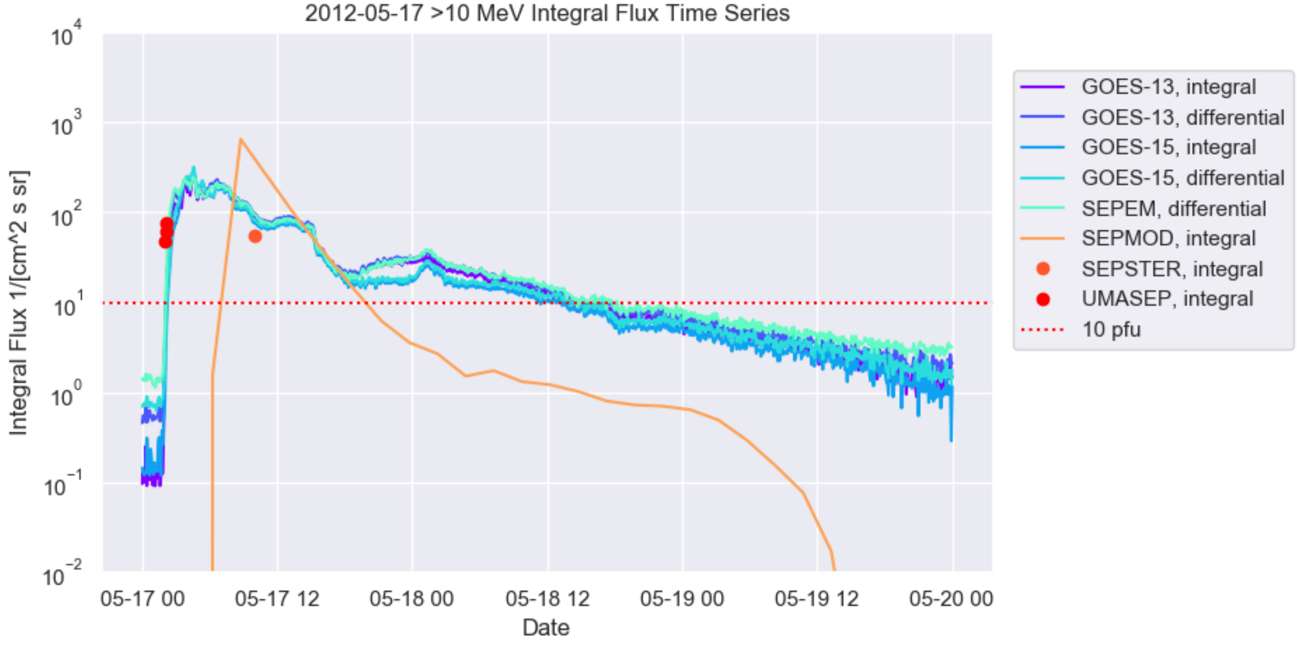
Model Predictions

Early/Low   Similar to Data   Late/High

Model	Start Time	Difference
SEPMOD	08:45:00	**+6 hr 35 min**
UMASEP	02:05:00 – 04:05:00	**-5 , +115 min**

Forecast: SEP Time Profile for >10 MeV protons
May 17, 2012 (>10 MeV exceeds 10 pfu)

Full Time Profile



SEPSTER peak time is more likely associated with the onset peak of 14 – 24 MeV and not the ESP peak. It is likely that the 14 – 24 MeV peak time is a good proxy for the >10 MeV peak time.

End Time and Duration

Operational Satellite: GOES-13, >10 MeV channel
End Time: 2012-05-18 17:45:00
Duration: 39.58 hours (1 day, 15 hrs, 35 mins)

Model Predictions

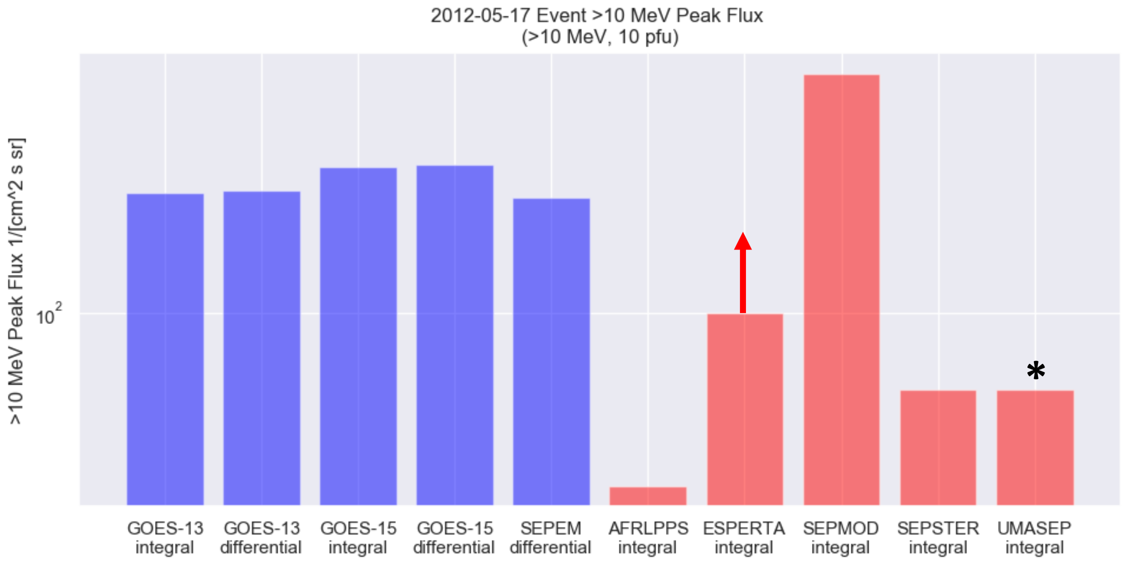
Early/Low Similar to Data Late/High

Model	End Time	Difference
SEPMOD	2012-05-17 21:15:00	-20.5 hours

Model	Duration	Difference
SEPMOD	12.5 hours	-27.08 hours

Forecast: SEP Peak Flux for >10 MeV protons
May 17, 2012 (>10 MeV exceeds 10 pfu)

Peak Flux



AFRL PPS and SEPSTER underpredict this event.
ESPERTA accurately predicts that the event exceeds S2 (>100 pfu).
*UMASEP results pertain to the start of the event, so are lower.
✯SEPSTER peak time prediction is more likely associated with the onset peak of 14 – 24 MeV.
SEPMOD start and peak time are the same, resulting in a rise time of 0 hours.

Peak Time and Rise Time

Operational Satellite: GOES-13, >10 MeV channel
Time of Peak: **2012-05-17 04:30:00**
Rise Time: **2.33 hours (2 hrs, 20 mins)**

Model Predictions

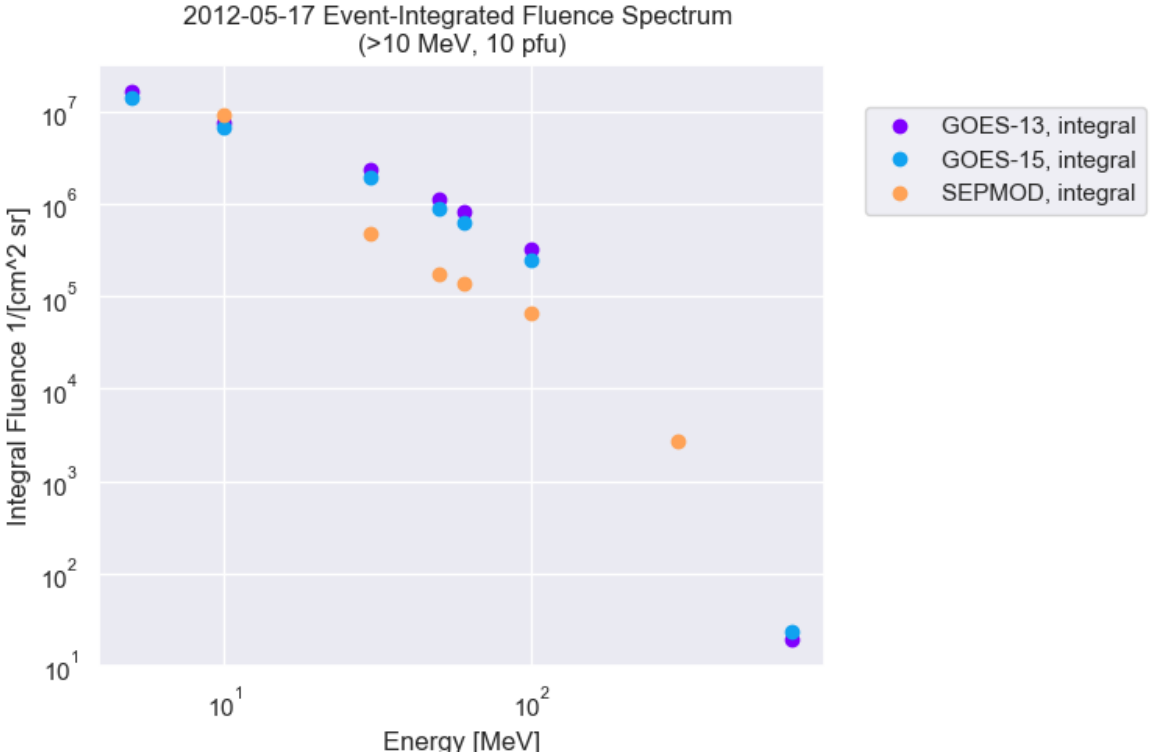
Early/Low | Similar to Data | Late/High

Model	Peak Time	Difference
SEPMOD	08:45:00	+4.25 hours
SEPSTER	09:58:00	+5.47 hours

Model	Rise Time	Difference
SEPMOD	0 hours	-2.33 hours

Forecast: SEP Fluence for >10 MeV protons
May 17, 2012 (>10 MeV exceeds 10 pfu)

Event-Integrated Fluence



SEPMOD predicts a shorter event and has a high >10 MeV fluence, but lower fluence for the higher energy channels.

>10 MeV Event-Integrated Fluence

Operational Satellite: GOES-13, >10 MeV channel
>10 MeV Fluence: 9.61e7 cm^{-2}

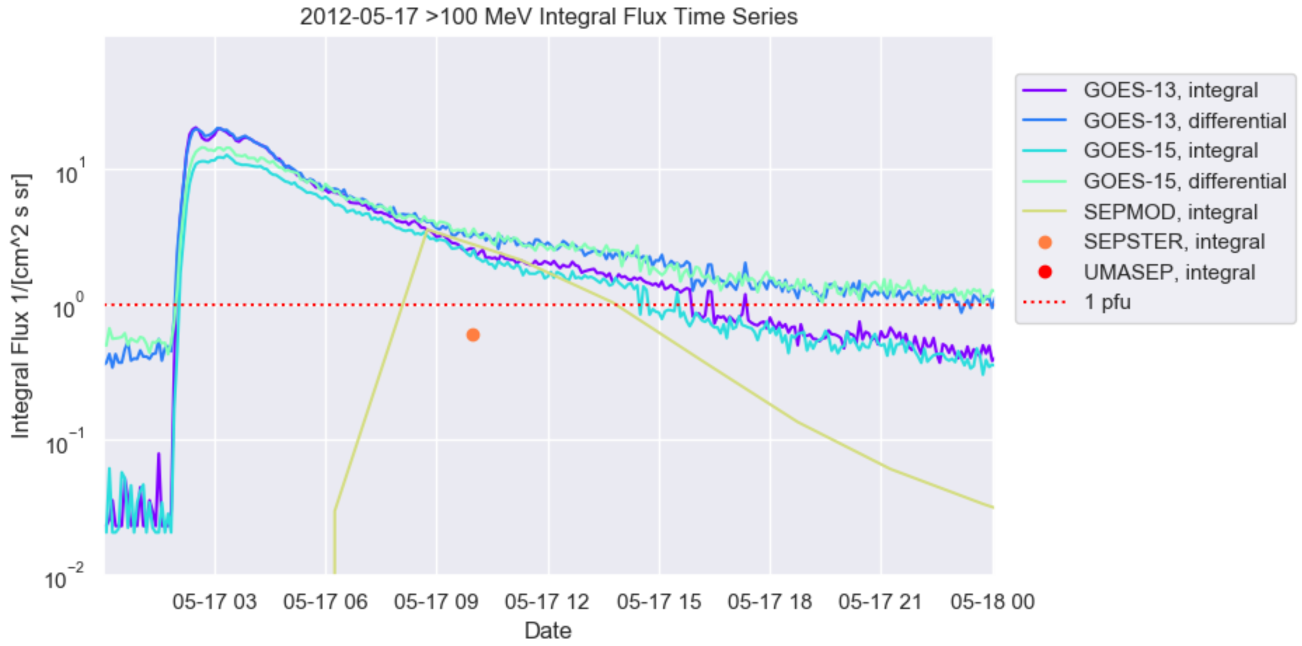
Model Predictions

Early/Low | Similar to Data | Late/High

Model	>10 MeV Fluence	Difference
SEPMOD	1.16e8 cm^{-2}	+20.7%

Forecast: SEP Onset for >100 MeV protons
May 17, 2012 (>100 MeV exceeds 1 pfu)

Onset Time Profile



UMASEP predicted no event for >100 MeV – MISS.

SEPMOD starts at $21R_{sun}$ and uses a 2.5 hour time resolution, which likely increases the delay in start time.

Note that the SEPSTER peak time in this plot is more pertinent to the >10 MeV channel, but is used here as an estimate.

Start Time

Operational Satellite: GOES-13, >100 MeV channel

Start Time: 2012-05-17 02:00:00

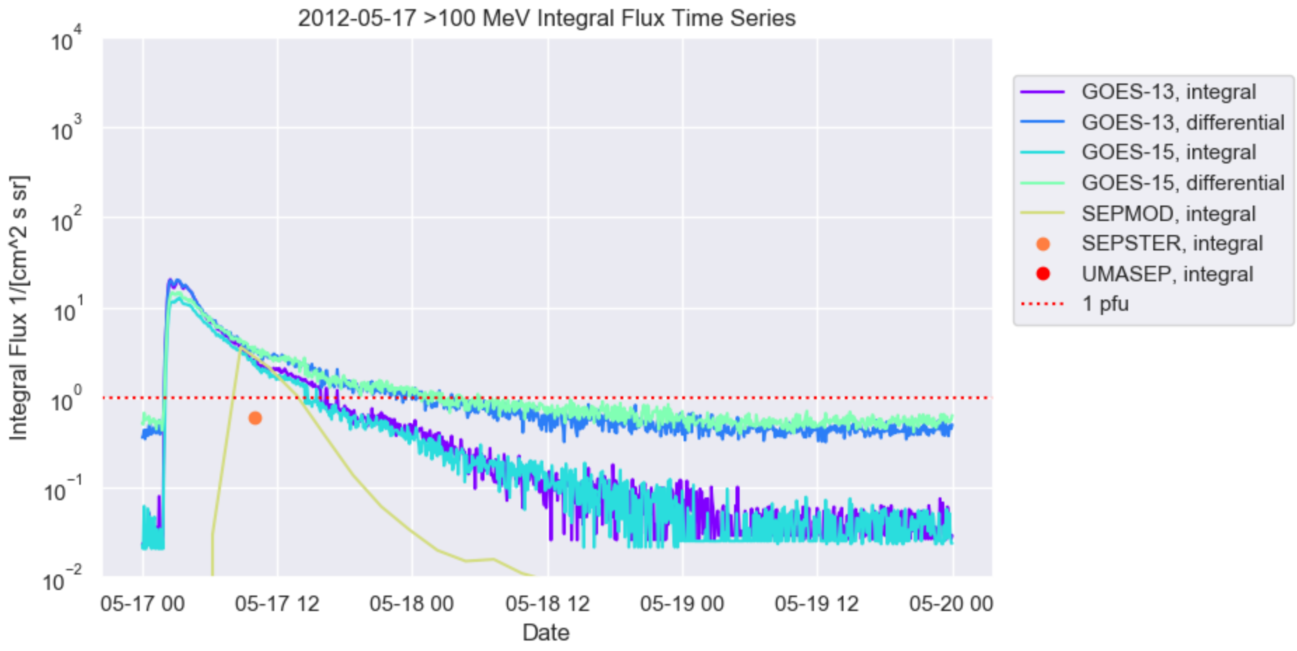
Model Predictions

Early/Low   Similar to Data   Late/High

Model	Start Time	Difference
SEPMOD	2012-05-17 08:45:00	+6 hr 45 min
UMASEP	-	**MISS**

Forecast: SEP Time Profile for >100 MeV protons
May 17, 2012 (>100 MeV exceeds 1 pfu)

Full Time Profile



UMASEP predicted no event for >100 MeV.
The SEPSTER peak time in this plot is more pertinent to the >10 MeV channel, but is used here as a broad estimate.

End Time and Duration

Operational Satellite: GOES-13, >100 MeV channel
End Time: 2012-05-17 16:30:00
Duration: 14.5 hours (14 hrs, 30 mins)

Model Predictions

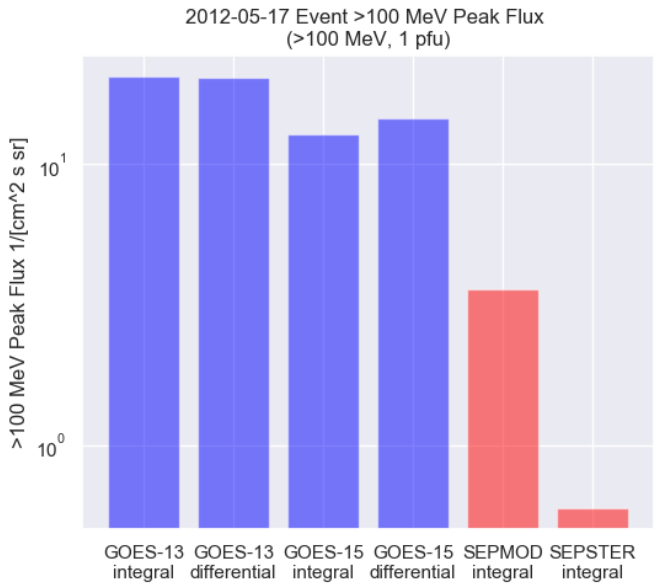
Early/Low | Similar to Data | Late/High

Model	End Time	Difference
SEPMOD	2012-05-17 16:15:00	**-15 mins**

Model	Duration	Difference
SEPMOD	7.5 hours	**-7 hours**

Forecast: SEP Peak Flux for >100 MeV protons
May 17, 2012 (>100 MeV exceeds 1 pfu)

Peak Flux



SEPSTER under-predicts this event.
UMASEP predicted no event for >100 MeV – MISS.
✯SEPSTER peak time is more associated with the onset peak of 14 – 24 MeV energies. It is included here out of interest.

Peak Time and Rise Time

Operational Satellite: GOES-13, >100 MeV channel
Time of Peak: **2012-05-17 02:30:00**
Rise Time: **0.5 hours (30 mins)**

Model Predictions

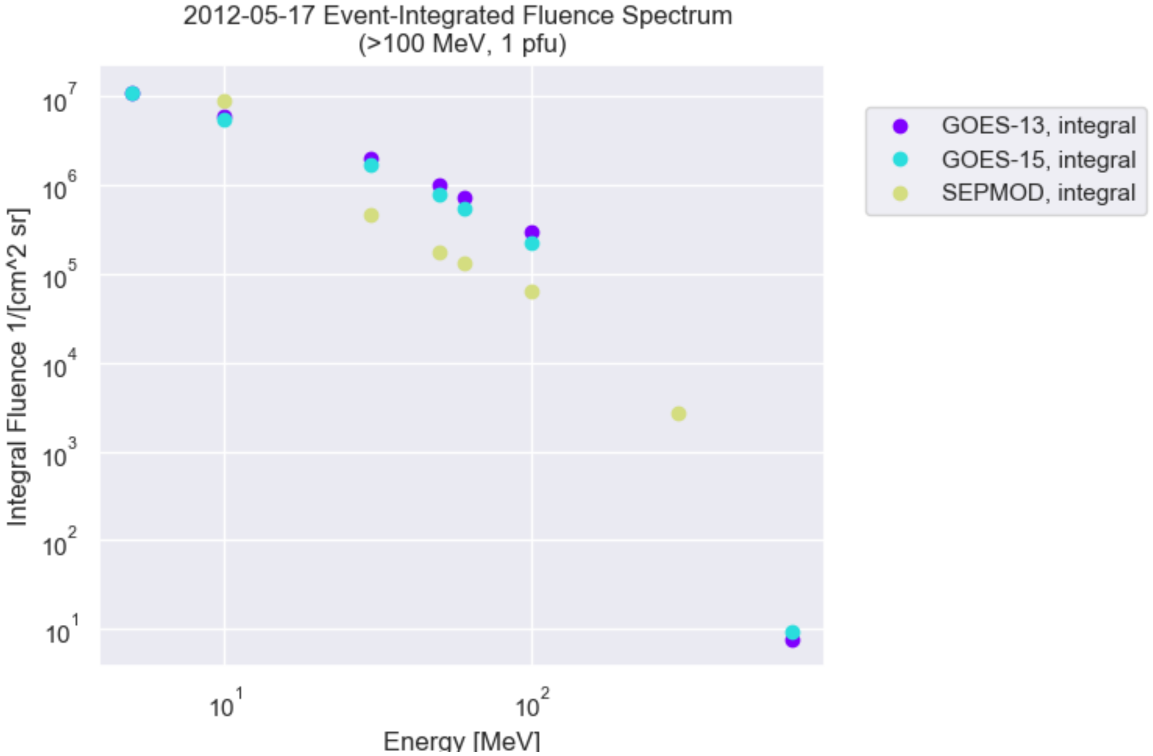
Early/Low | Similar to Data | Late/High

Model	Peak Time	Difference
SEPMOD	2012-05-17 08:45:00	+6.25 hours
SEPSTER	09:58:00✯	+7.47 hours

Model	Rise Time	Difference
SEPMOD	0 hours	-30 minutes

Forecast: SEP Fluence for >100 MeV protons
May 17, 2012 (>100 MeV exceeds 1 pfu)

Event-Integrated Fluence



SEPMOD predicts a shorter event and has a lower overall fluence, however the spectral shape is reasonable.

>100 MeV Event-Integrated Fluence

Operational Satellite: GOES-13, >100 MeV channel
>100 MeV Fluence: 3.79e6 cm^{-2}

Model Predictions

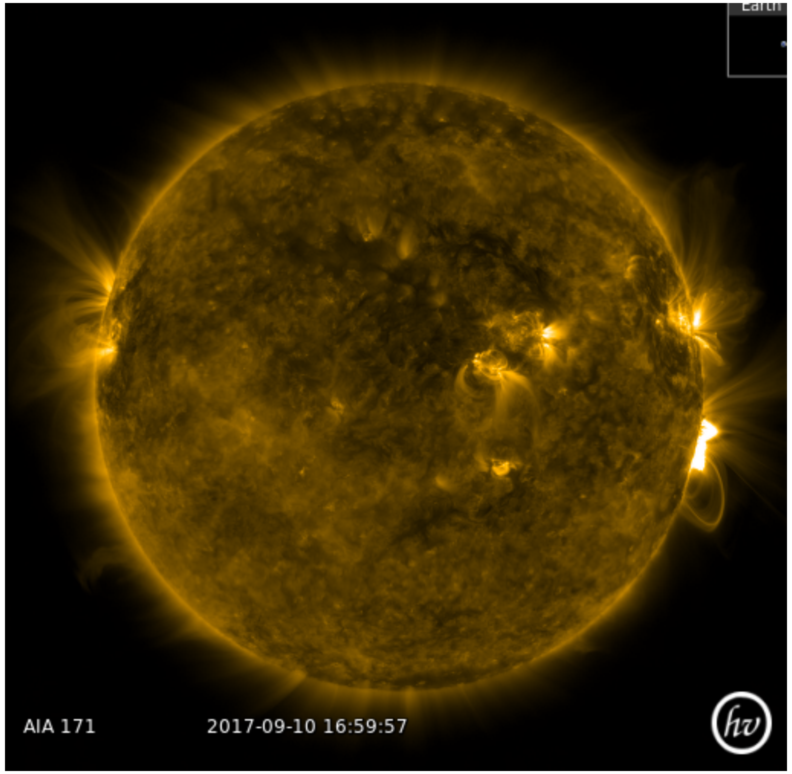
Early/Low   Similar to Data   Late/High

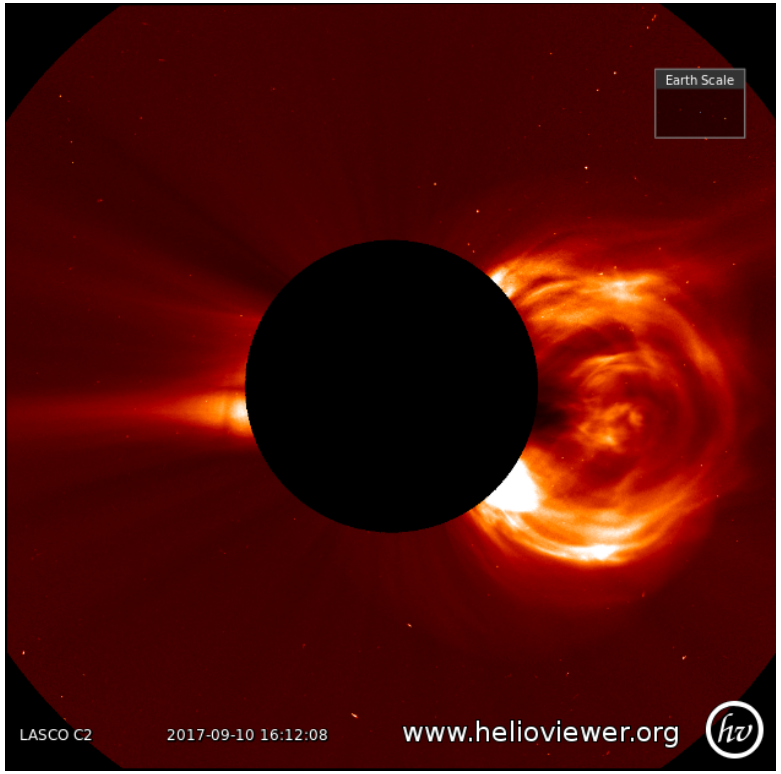
Model	>100 MeV Fluence	Difference
SEPMOD	8.11e5 cm^{-2}	-78.6%

Predictions from AFRL PPS, ESPERTA, SEPMOD, SEPSTER, STAT, UMASEP

September 10, 2017

September 10, 2017 SEP Event



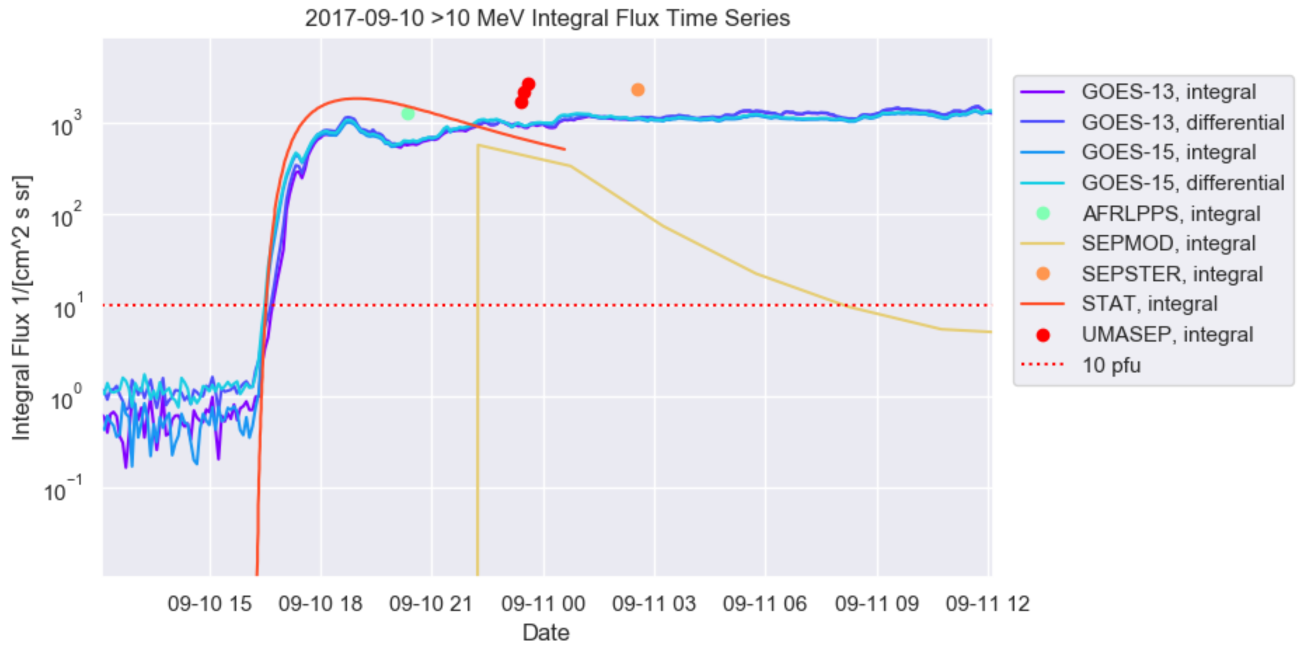


Flare Class	Start	Peak	End	NOAA AR	LAT	LON
X8.2	15:35	16:06	16:31	12673	S08	W88

CME Speed (km/s)	CME Width	First Appearance Time (LASCO C2)
3163	Halo	16:00:05

Forecast: SEP Onset for >10 MeV protons
September 10, 2017 (>10 MeV exceeds 10 pfu)

Onset Time Profile



SEPMOD starts at 21R_{sun} and uses a 2.5 hour time resolution, which likely increases the delay in start time.
STAT performs well in the first few hours of simulation prior to the CME approaching the MAS 30R_{sun} outer domain.
UMASEP predicts a flux range close to the peak, which is in the prediction window.

Start Time

Operational Satellite: GOES-13, >10 MeV channel
Start Time: 2017-09-10 16:45:00

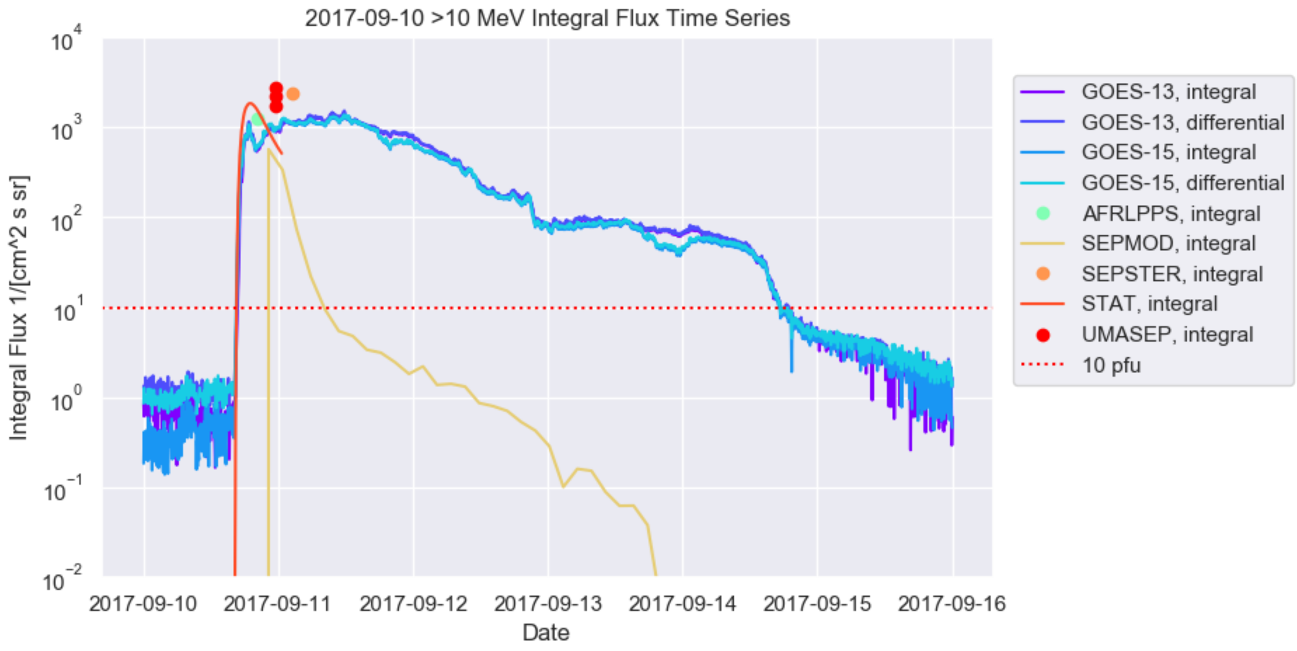
Model Predictions

Early/Low Similar to Data Late/High

Model	Start Time	Difference
SEPMOD	22:15:00	+6.5 hours
STAT	16:32:31	-12.5 mins
UMASEP	16:30:00 – 18:30:00	-15, +105 min

Forecast: SEP Time Profile for >10 MeV protons
September 10, 2017 (>10 MeV exceeds 10 pfu)

Full Time Profile



The inclusion of STAT and SEPMOD result in an interesting comparison. STAT covers the solar domain out to about 30 R_{sun} while SEPMOD begins with the ENLIL domain at 21 R_{sun}. We can see how STAT covers the event onset, while SEPMOD picks up later in the event as the CME propagates.

End Time and Duration

Operational Satellite: GOES-13, >10 MeV channel
End Time: 2017-09-14 18:50:00
Duration: 98.08 hours (4 days, 2 hrs, 5 mins)

Model Predictions

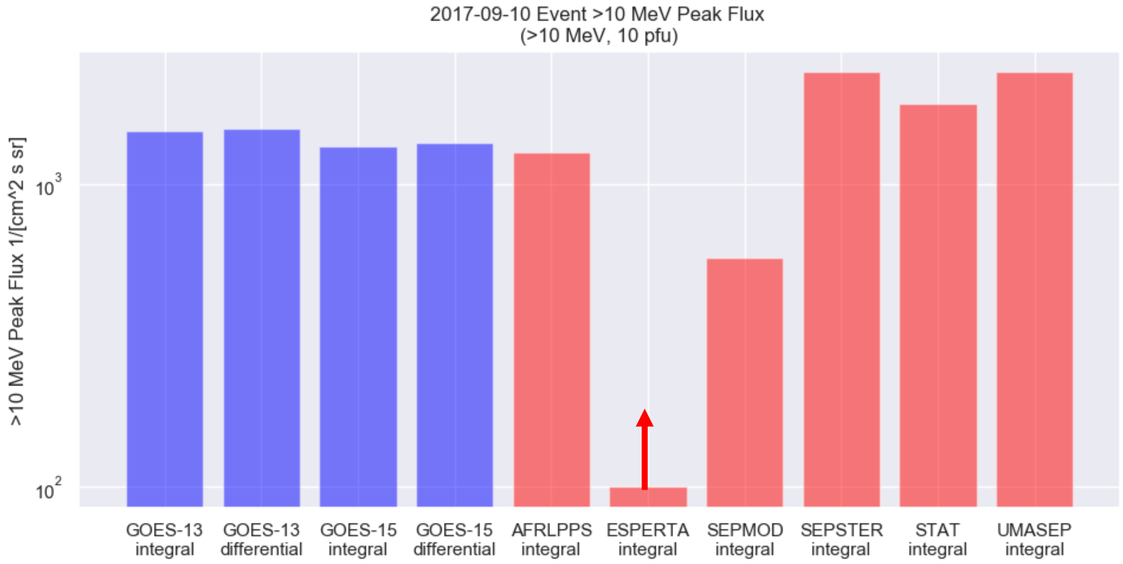
Early/Low | Similar to Data | Late/High

Model	End Time	Difference
SEPMOD	2017-09-11 10:45:00	-3 days 8.08 hr

Model	Duration	Difference
SEPMOD	12.5 hours	-85.58 hours

Forecast: SEP Peak Flux for >10 MeV protons
September 10, 2017 (>10 MeV exceeds 10 pfu)

Peak Flux



All of the models are more accurate with this well-connected event.
ESPERTA accurately predicts that the event exceeds S2 (>100 pfu).
UMASEP prediction window near to peak, so predicted max flux can be compared to peak flux.
✯STAT estimates only the onset peak flux and time and does not model the ESP.
✯SEPSTER peak time is more likely associated with the onset peak of 14 – 24 MeV and not the ESP peak. In this analysis, no effort was taken to differentiate between the two.

Peak Time and Rise Time

Operational Satellite: GOES-13, >10 MeV channel
Time of Peak: **2017-09-11 11:45:00**
Rise Time: **19 hours**

Model Predictions

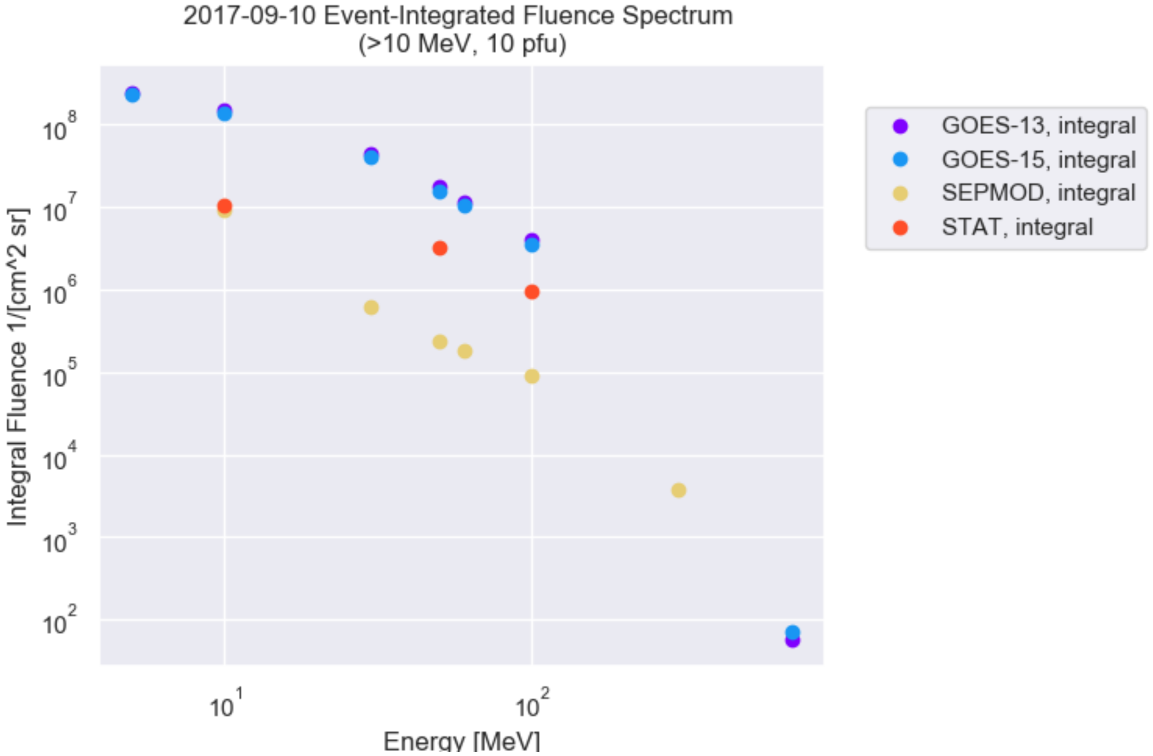
Early/Low | Similar to Data | Late/High

Model	Peak Time	Difference
SEPMOD	2017-09-10 22:15:00	-13.5 hours
SEPSTER	2017-09-11 02:33:00✯	-9.2 hours
STAT	2017-09-10 18:51:19✯	-16.9 hours

Model	Rise Time	Difference
SEPMOD	0 hours	-19 hours

Forecast: SEP Fluence for >10 MeV protons
September 10, 2017 (>10 MeV exceeds 10 pfu)

Event-Integrated Fluence



SEPMOD predicts a shorter event and has a lower overall fluence, however the spectral shape is reasonable.
STAT only predicts the beginning of the event, but almost captures the peak.

>10 MeV Event-Integrated Fluence

Operational Satellite: GOES-13, >10 MeV channel
>10 MeV Fluence: 1.89e9 cm^{-2}

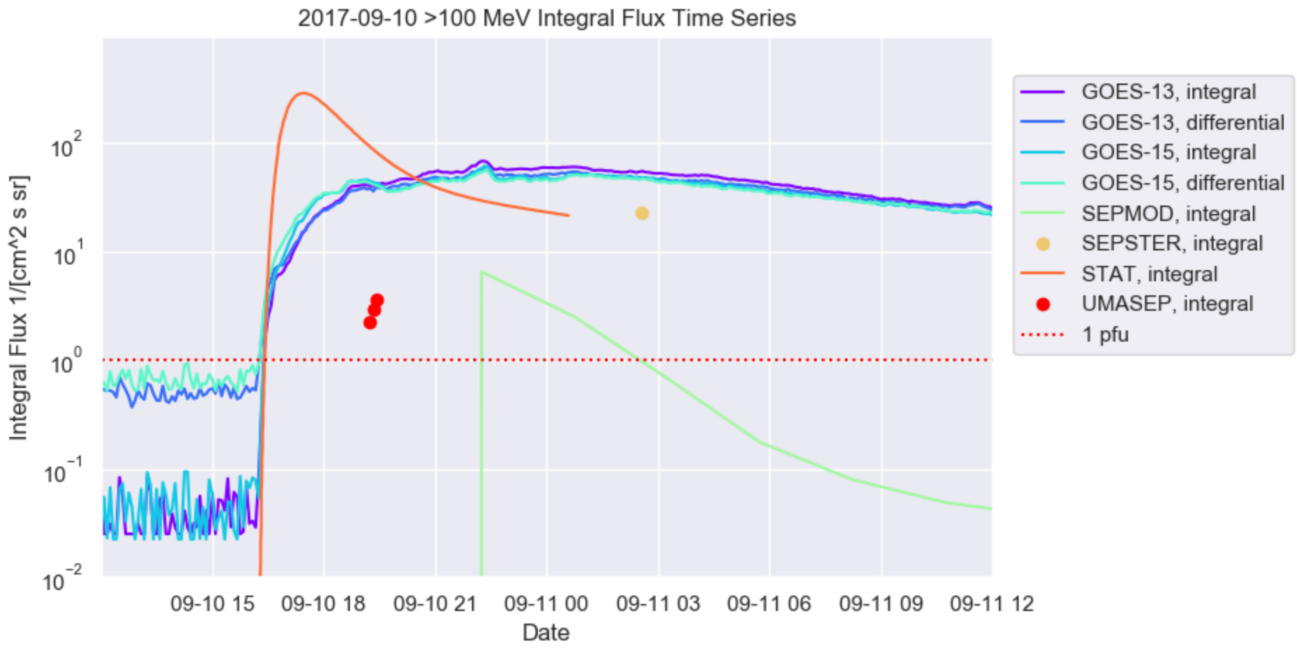
Model Predictions

Early/Low | Similar to Data | Late/High

Model	>10 MeV Fluence	Difference
SEPMOD	1.15e8 cm^{-2}	-93.9%
STAT	1.31e8 cm^{-2}	-93.1%

Forecast: SEP Onset for >100 MeV protons
September 10, 2017 (>100 MeV exceeds 1 pfu)

Onset Time Profile



SEPMOD starts at $21R_{sun}$ and uses a 2.5 hour time resolution.
STAT performs well in the first few hours of simulation prior to the CME approaching the MAS $30R_{sun}$ outer domain.
Note that the SEPSTER peak time in this plot is more pertinent to the >10 MeV channel, but is used here as an estimate.

Start Time

Operational Satellite: GOES-13, >100 MeV channel
Start Time: **2017-09-10 16:25:00**

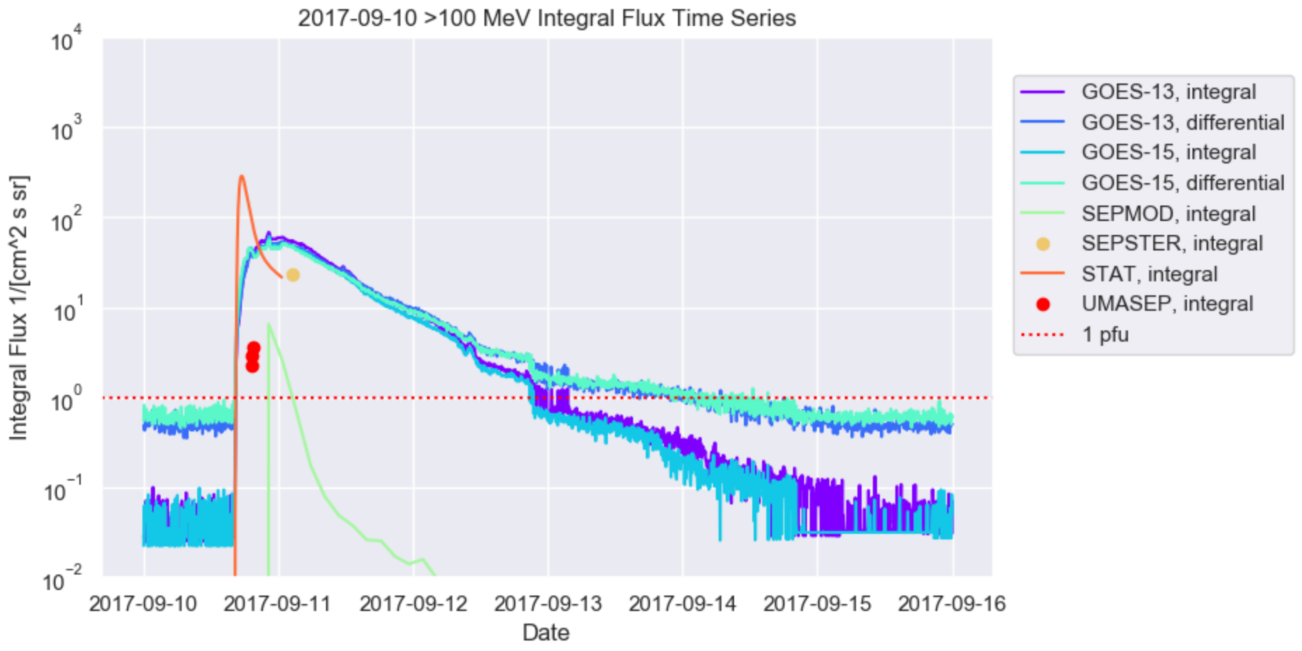
Model Predictions

Early/Low | Similar to Data | Late/High

Model	Start Time	Difference
SEPMOD	22:15:00	**+5hrs 50 mins**
STAT	16:25:17	**0 mins**
UMASEP	16:20:00 – 18:20:00	**-5, +115 mins**

Forecast: SEP Time Profile for >100 MeV protons
September 10, 2017 (>100 MeV exceeds 1 pfu)

Full Time Profile



Note that the SEPSTER peak time in this plot is more pertinent to the >10 MeV channel, but is used here as a broad estimate.

STAT covers the solar domain out to about 30 R_{sun} while SEPMOD begins with the ENLIL domain at 21 R_{sun}. We can see how STAT covers the event onset, while SEPMOD picks up later in the event as the CME propagates.

End Time and Duration

Operational Satellite: GOES-13, >100 MeV channel

End Time: 2017-09-12 22:40:00

Duration: 54.25 hours (2 days, 6 hrs, 15 mins)

Model Predictions

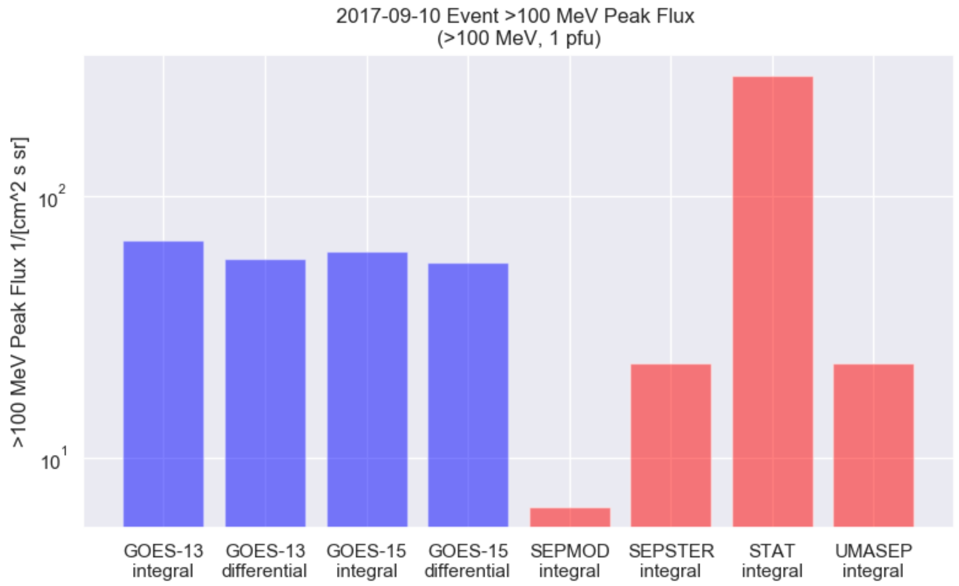
Early/Low Similar to Data Late/High

Model	End Time	Difference
SEPMOD	2017-09-11 03:15:00	-43.42 hours

Model	Duration	Difference
SEPMOD	5 hours	-49.25

Forecast: SEP Peak Flux for >100 MeV protons
September 10, 2017 (>100 MeV exceeds 1 pfu)

Peak Flux



SEPMOD under-predicts this event, mostly because it misses the beginning.
STAT predictions in range of event peak, so peak prediction can be compared to data.
UMASEP prediction window near to peak, so predicted max flux can be compared to peak flux.
The SEPSTER peak time in this plot is more pertinent to the >10 MeV channel, but is used here as a broad estimate.

Peak Time and Rise Time

Operational Satellite: GOES-13, >100 MeV channel
Time of Peak: 2017-09-10 22:15:00
Rise Time: 5.83 hours (5 hrs 50 mins)

Model Predictions

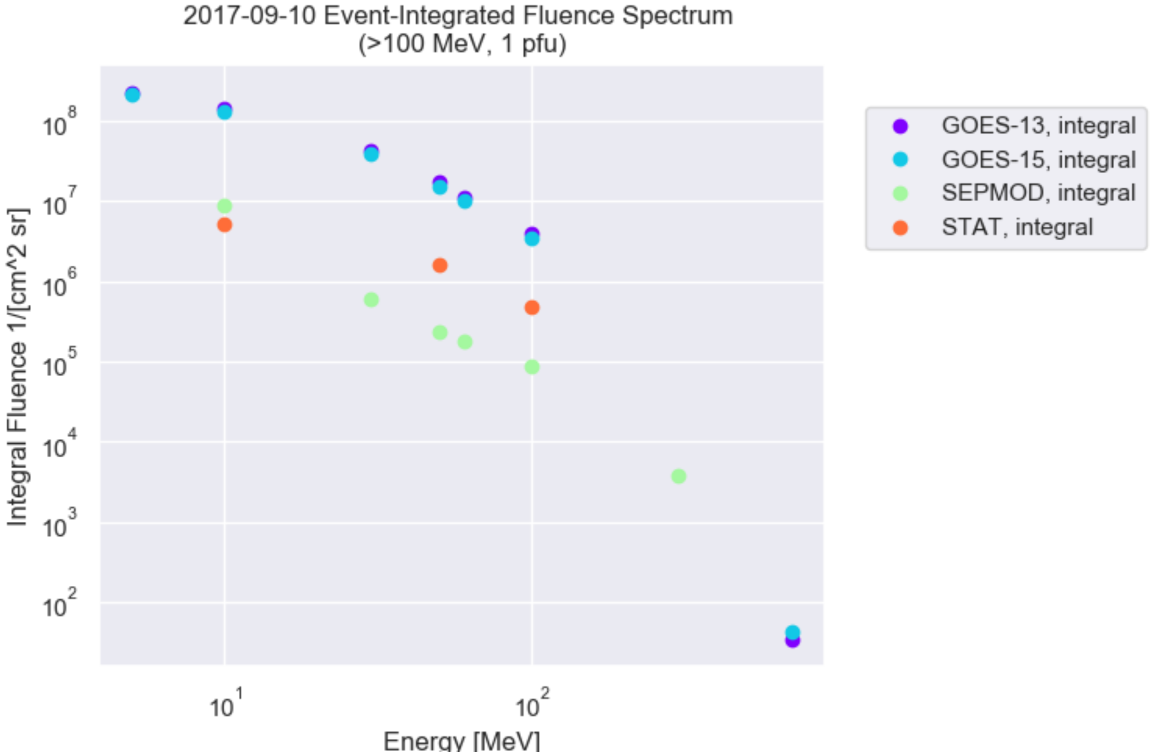
Early/Low   Similar to Data   Late/High

Model	Peak Time	Difference
SEPMOD	2017-09-10 22:15:00	0 hours
SEPSTER	2017-09-11 02:33:00	+4.3 hours
STAT	2017-09-10 17:26:59	-4.8 hours

Model	Rise Time	Difference
SEPMOD	0 hours	-5.83 hours
STAT	1.02 hours	-4.81 hours

Forecast: SEP Fluence for >100 MeV protons
September 10, 2017 (>100 MeV exceeds 1 pfu)

Event-Integrated Fluence



SEPMOD predicts a shorter event and has a lower overall fluence, however the spectral shape is reasonable.
STAT includes only the beginning of the event, but captures much of the fluence.

>100 MeV Event-Integrated Fluence

Operational Satellite: GOES-13, >100 MeV channel
>100 MeV Fluence: 4.91e7 cm^{-2}

Model Predictions

Early/Low | Similar to Data | Late/High

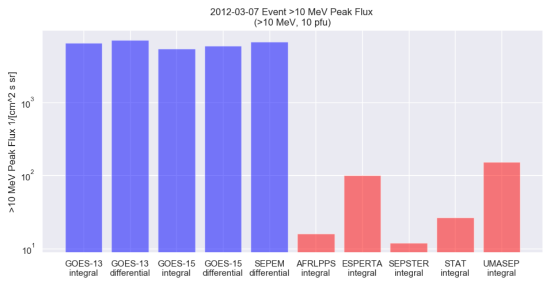
Model	>100 MeV Fluence	Difference
SEPMOD	1.10e6 cm^{-2}	-97.8%
STAT	6.02e6 cm^{-2}	-87.7%

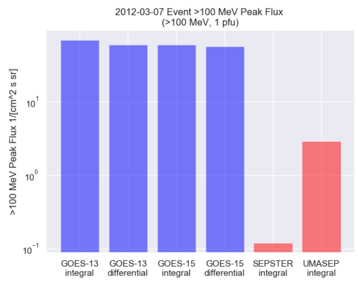
Discussion – Peak Flux Models

- The peak flux models AFRL PPS and SEPSTER heavily underestimated the peak for the poorly-connected, very strong gradual event of March 7, 2012.
- The peak flux predictions performed better for the western, well-connected events, especially September 10, 2017.
- All models need improvement for the peak flux prediction of high energy >100 MeV fluxes.

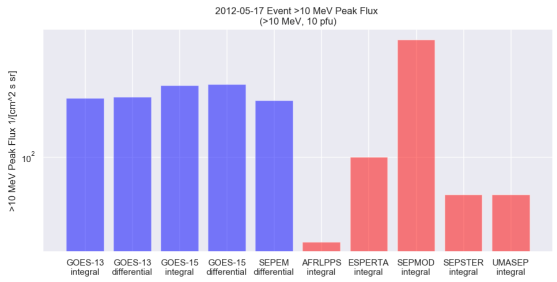
>10 MeV Peak Fluxes | **>100 MeV Peak Fluxes**

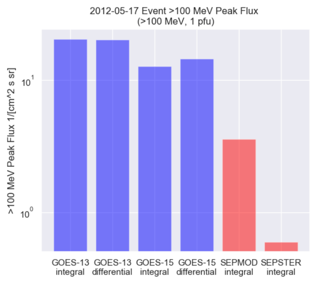
March 7, 2012



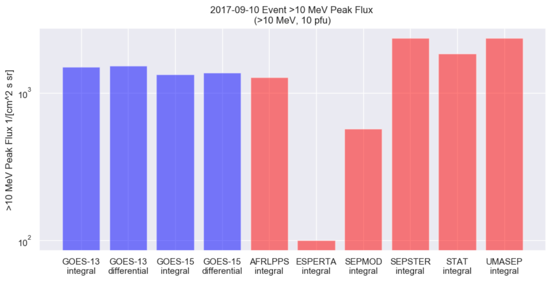


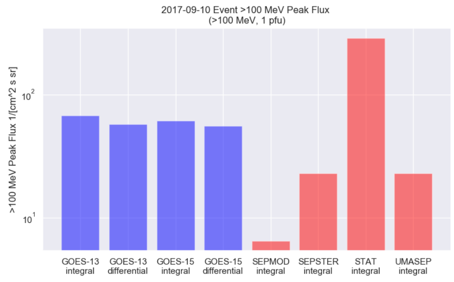
May 17, 2012





September 10, 2017



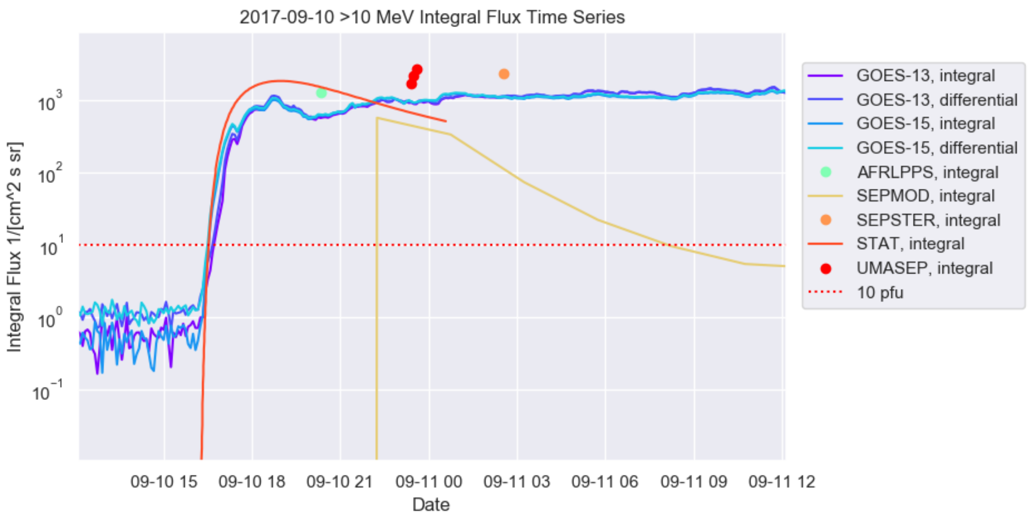


Discussion – UMASEP

- UMASEP is a unique model that forecasts the maximum flux within a specific time window after the start of the event.
- UMASEP’s flux predictions were very good for >10 MeV for all events.
- The flux predictions were not as accurate for >100 MeV, but the model accurately predicted a threshold crossing for 2/3 events. (Missed the May 17, 2012 event.)
- For quick-rise, well-connected events, UMASEP’s prediction could be considered a peak flux prediction.

Discussion – Time-Profile Models

- In the current state, STAT could be used to predict particle rise for the first few hours of an event, while SEPMOD could be used to look at event evolution starting a few hours into the event.
- STAT might be used to predict peak flux for quick-rise, well-connected events.
- SEPMOD generally missed peak flux for these events. SEPMOD does predict an ESP component and may have success estimating >10 MeV peak fluxes produced by ESPs, but the two events simulated by SEPMOD here did not have strong ESPs.
- Viewing STAT and SEPMOD together highlight the importance of simulating the full solar domain – corona and solar wind out to 1 AU – in order to capture the full event profile with physics-based particle transport models.



Discussion – Seed Population

- Seed population is an important but poorly-determined quantity for physics-based models.
- Physics-based SEP models must assume a spectral shape for the seed population and then typically adjust the fluence level by a normalization factor until the model results match the data.
- This required normalization step reduces the forecasting capability of this type of model.
- For the March 7, 2012 event: STAT performed well for the >10 MeV fluxes, but underestimated the >100 MeV fluxes and did not predict a threshold crossing (MISS).
- For the Sept. 10, 2017 event: STAT performed very well in both energy channels.
- Part of this discrepancy may arise from differences in seed population environment at the sun prior to the start of the two events that was not captured in the model.