ISWAT H3-01: SEP MODEL VALIDATION

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NASA JSC Space Radiation Analysis Group

CCMC Workshop

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H3-01: SEP MODEL VALIDATION

Team title: SEP Validation

Team ID: H3-01

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Keywords (impact): Human exploration

Keywords (activity type): Forecasting, Assessment,

- Initial campaigns in SHINE 2018 and ESWW 2018
- SHINE 2019 & ISWAT 2021: 10 Challenge SEP events
- ISWAT 2020: Validation approach
- Upcoming SHINE 2022: 14 Challenge "non-events"
- ISWAT: https://iswat-cospar.org/H3-01
- CCMC: https://ccmc.gsfc.nasa.gov/challenges/sep/
- SHINE 2022 Events: https://helioshine.org/sep-model-validation-challenge/

Home › Community Challenges

Last Updated: 05/18/2022

SHINE/ISWAT/ESWW SEP Model Validation Challenge

Organizers

Organizers: Katie Whitman (NASA JSC SRAG/University of Houston), Hazel Bain (NOAA SWPC/CU Boulder CIRES), Leila Mays (NASA Goddard), Phil Quinn (NASA JSC SRAG), Ian Richardson (NASA Goddard/University of Maryland), Mark Dierckxsens (BIRA-IASB)

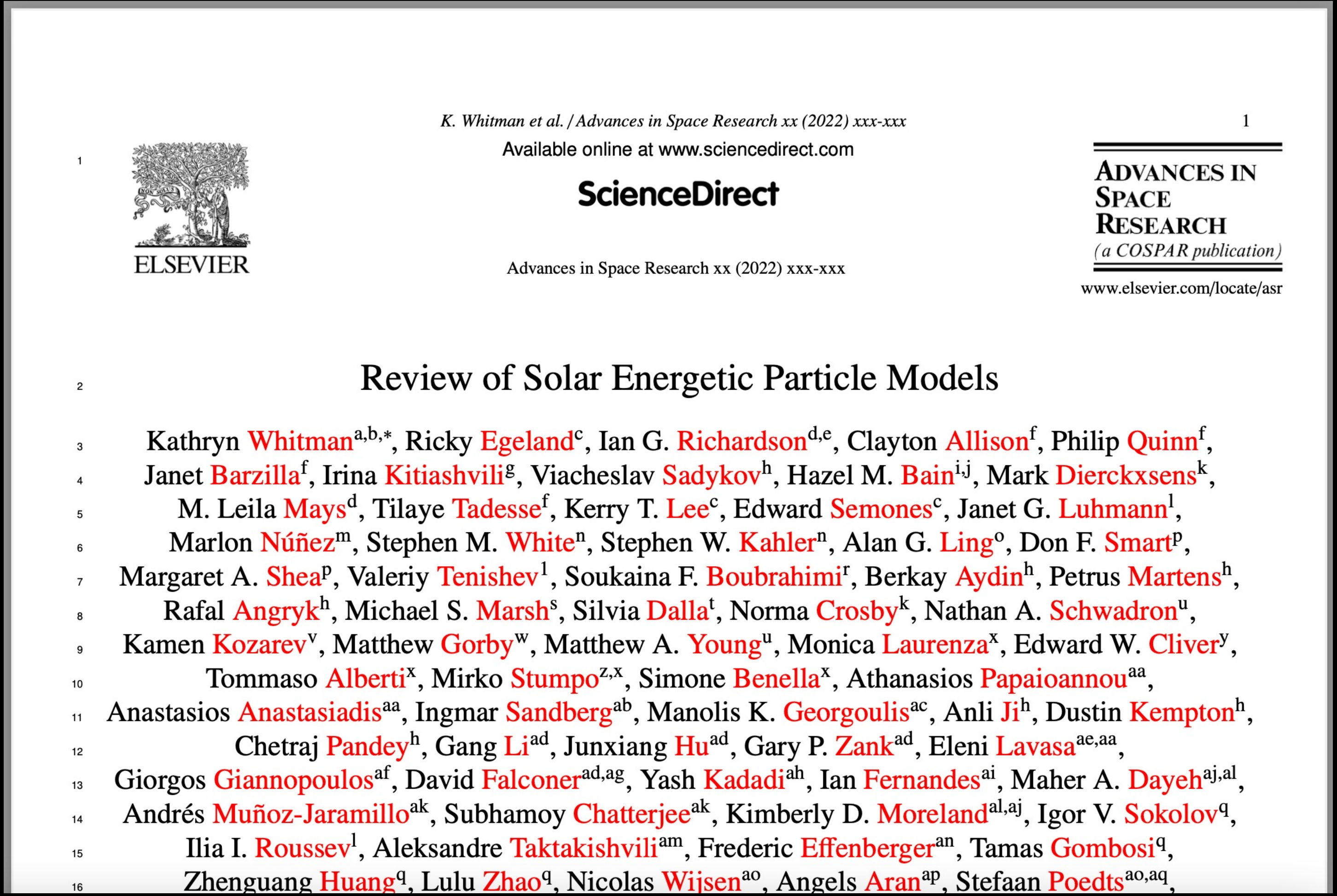
Introduction

This website was created to provide SEP modelers with all the information needed to participate in the SHINE/ISWAT/ESWW SEP Model Validation

Sections in this page

- Organizers
- Introduction
- GOALS
- Progress and Status
  - Current Status
  - Next Steps
- Approach for Validation Effort
- Participating Models
- Standard Inputs

REVIEW OF SOLAR ENERGETIC PARTICLE MODELS


K. Whitman et al. / Advances in Space Research xx (2022) xxx-xxx 1

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Advances in Space Research xx (2022) xxx-xxx

Advances in Space Research (a COSPAR publication)

www.elsevier.com/locate/asr

Review of Solar Energetic Particle Models

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- Whitman et al. submitted to special issue of Advances in Space Research for the ISWAT-COSPAR heliophyiscs roadmap effort
- Summarize 35 SEP models in the community with over 100 coauthors
  - Inputs/Outputs
  - Caveats
  - Validation
- Emphasize critical observations required to run and validate SEP models and their limitations
- Compile outputs of each model to understand forecasting coverage and identify gaps

Table 11: Outputs produced by the solar energetic particle models summarized in this paper. Pre/Post: Pre indicates pre-eruptive forecast prior to the flare or CME, Post indicates a forecast issued after an eruptive event (flare, CME) has occurred; All Clear: binary yes/no forecast for an SEP event or specific threshold crossing; Probability: probability of occurrence; Flux Point: forecast of proton intensity levels for a single time point or a single flux value within a specific time window in the future (see main text for further description); Onset time: time of threshold crossing or SEP event start; Peak: peak intensity; Peak time: time of the peak intensity; End time: event end time or decay time; Fluence: total event time-integrated fluence; Time profile: produces intensity with time; Multi loc.: capable of producing forecasts for multiple locations in the heliosphere; 3D: produces 3D environmental data and particle info, such as pitch angle distributions. If a model outputs a time profile, then it is indicated that the model predicts onset time, peak flux and time, end time, and fluence as applicable. There are some time profile models that cannot currently simulate the full duration of the event and for these, only the predictions that are possible to derive from their time profiles are indicated.

Model	Proton Energy [MeV]	Pre/Post	All Clear	Probability	Flux Point	Onset time	Peak	Peak time	End time	Fluence	Time profile	Multi loc.	3D
ADEPT	>10, >30, >50, >100	Post					x	x	x	x	x		
AFRL PPS	>5, >10, >50	Post				x	x	x	x	x	x		
Aminalragia-Giamini model	≥5	Post	x	x									
AMPS	eV to GeV	Post				x	x	x	x	x	x	x	x
Boubrahimi model	>100	Post	x										
COMESEP SEPForecast	>10, >60	Post		x		x	x	x	x				
EPREM	5 - 1000**	Post				x	x	x	x	x	x	x	x
ESPERTA	>10	Post	x										
FORSPEF	>10, >30, >60, >100	Pre/Post		x		x	x	x	x	x			
GSU	>10	Pre	x	x									
iPATH	100 keV - GeV	Post				x	x	x	x	x	x	x	x
Lavasa Model	>10	Pre	x										
MAG4	>10	Pre	x	x									
MagPy	>10	Pre	x	x									
MEMPSEP	9-15, >5, >10, >30, >60, >100	Post		x		x	x	x	x	x			
M-FLAMPA	10 keV - 1 GeV	Post				x	x	x	x	x	x	x	x
PARADISE	keV - GeV	Post				x	x	x	x	x	x	x	x
PCA model	> 10	Post		x									
PROTONS	>10	Post		x			x	x					
REleASE	4-9; 9-15.8; 15.8-39.8; 28.2-50.1	Post		x	x								
Sadykov et al.	>10	Pre	x	x									
SAWS-ASPECS	>10 to >300	Pre/Post	x	x		x	x	x	x	x	x		
SEPCaster	100 keV - GeV	Post	x			x	x	x	x	x	x	x	x
SEPMOD	1 - 1000	Post					x	x	x		x	x	x
SEPSTER	14 - 24; >10, >30, >50, >100	Post					x	x				x	
SEPSTER2D	10 - 130; >130	Post					x	x	x	x		x	
SMARP Model	>10	Pre	x	x									
SOLPENCO(2)	0.125 - 64; 5 - 300	Post				x	x	x		x	x	x	
South African model	keV - GeV	Post				x	x	x	x	x	x	x	x
SPARX	>10, >60, >300	Post				x	x	x	x	x	x	x	x
SPREAdFAST	2 - 115	Post				x	x	x			x	x	x
SPRINTS	1, 5, 10, 30, 50, 100	Pre/Post	x	x									
STAT	1 - 1000	Post				x	x	x			x	x	x
UMASEP	>10, >30, >50, >100, >500	Post	x		x	x	x	x		x			
Zhang model	MeV - GeV	Post				x	x	x	x	x	x	x	x

Legend:
Forecasting in the SEP Scoreboard

SEP MODELS

- The research community has developed a wide variety of SEP models
- Only a few models are operational (6 on SEP Scoreboard, 5 in other operational settings)
- 9/35 models make pre-eruption forecasts
- Nearly every pre-eruption model applies machine learning
- Most pre-eruption forecasts are for >10 MeV; *>100 MeV is important for space radiation*
- Most models (26/35) make post-eruption forecasts
- Post-eruption forecasting is delayed by data latency (coronagraph, space-based radio), the manual process of measuring CME parameters, and/or run time (physics-based)
- UMASEP and REleASE provide post-eruption forecasts with advanced warning

Whitman et al. (2022), *Review of Solar Energetic Particle Models*, submitted to a special issue of ASR for the COSPAR Space Weather Roadmap

SEP DOSE IN DEEP SPACE – MERTENS AND SLABA (2019)

- Mertens, C. J., & Slaba, T. C. (2019). Characterization of solar energetic particle radiation dose to astronaut crew on deep-space exploration missions. *Space Weather*, *14* , 1650–1658. https://doi.org/10.1029/2019SW002363
- Used 65 historical SEP events to estimate dose inside the blood-forming organs (BFO) of an astronaut crew in the Orion vehicle in free space
- The free space spectra were transported through the Orion vehicle shielding of aluminum and polyethylene using HZETRN2015
- Additional mass for an SEP shelter was included
- Calculated BFO dose at 4 crew locations in the nominal and sheltered configurations

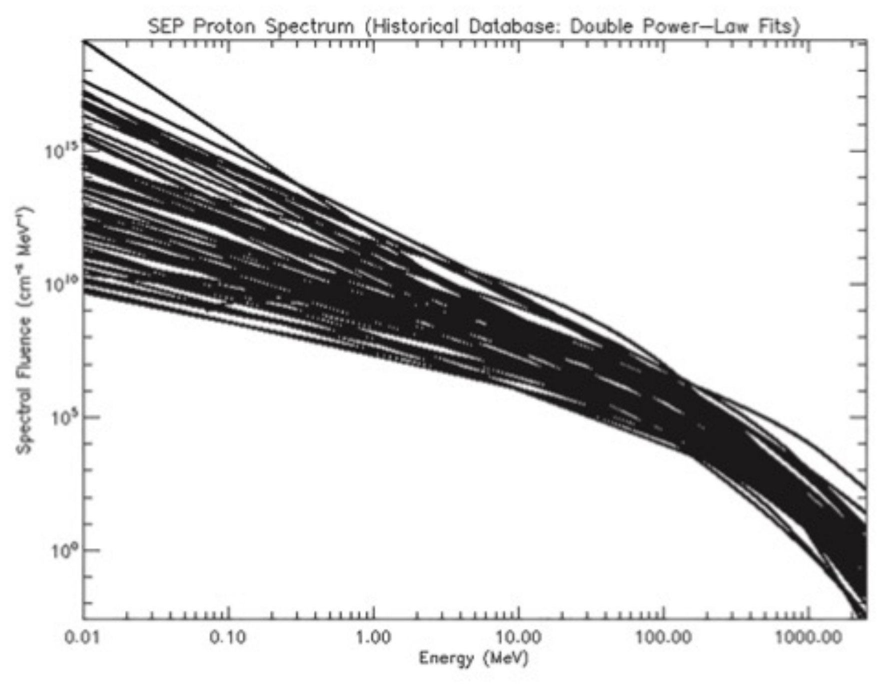


Figure 1. Proton spectral fluence profiles derived from a set of 65 historical SEP events. The fit parameters are tabulated by Raukunen et al. (2018). This figure also corresponds to Figure 1 of Mertens et al. (2018).

SEP DOSE IN DEEP SPACE – INSIDE A SHELTER

- For the sheltered configuration:
  - >100 MeV contributions to the total BFO dose are ~92% - 96%
  - >500 MeV contributions doubled for the sheltered configuration compared to the seated configuration
- Considering all 65 SEP events in the historical database, the Orion vehicle storm shelter reduced the BFO dose by 38% on average compared to the nominal, seated crew configuration.

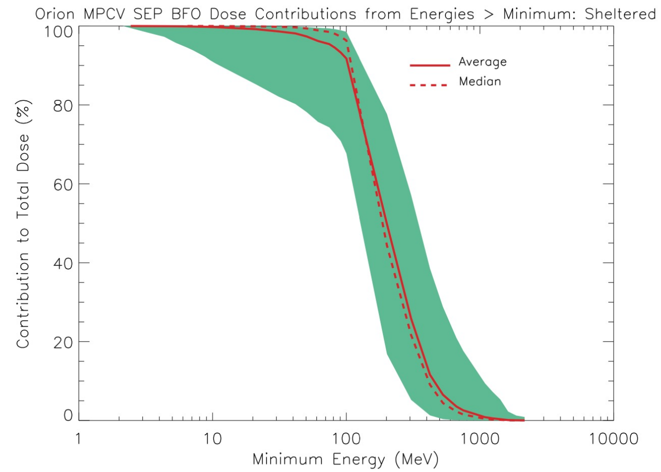
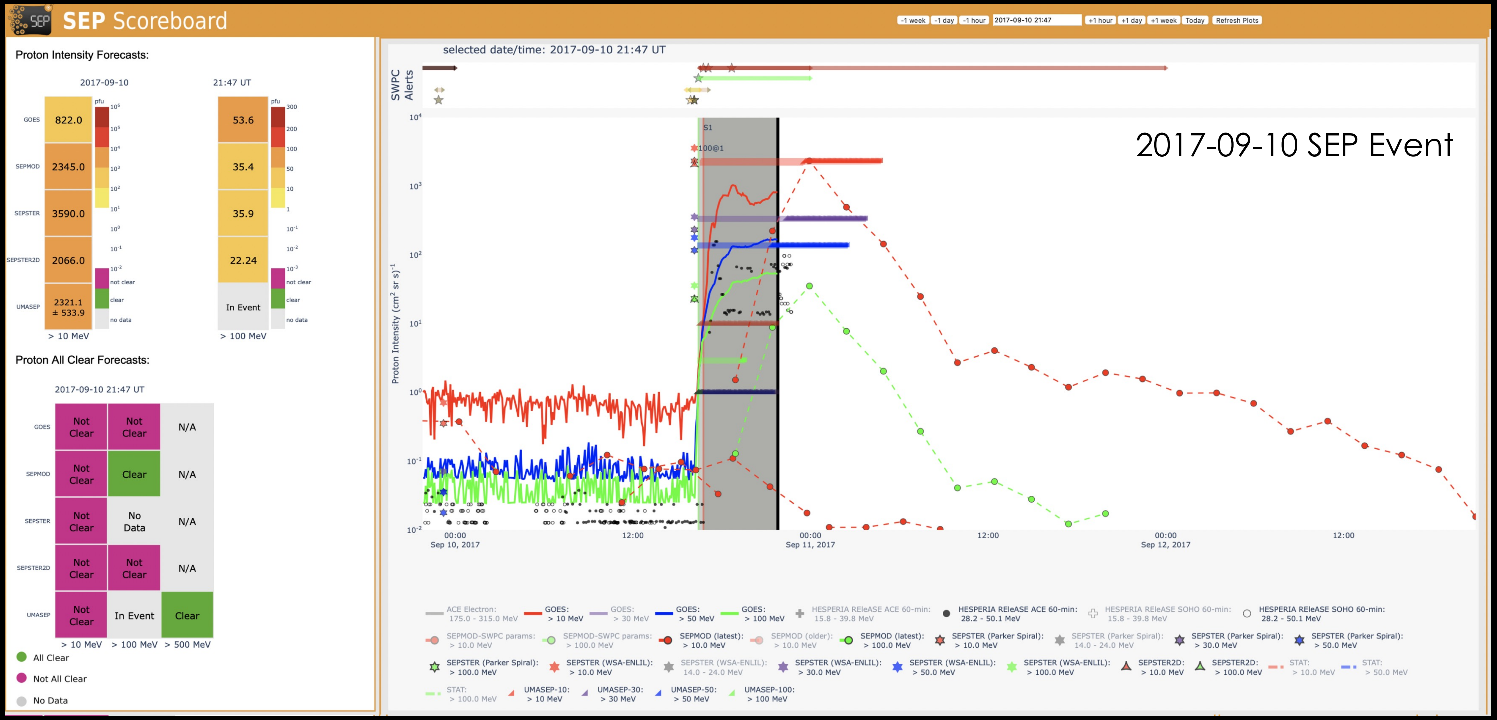


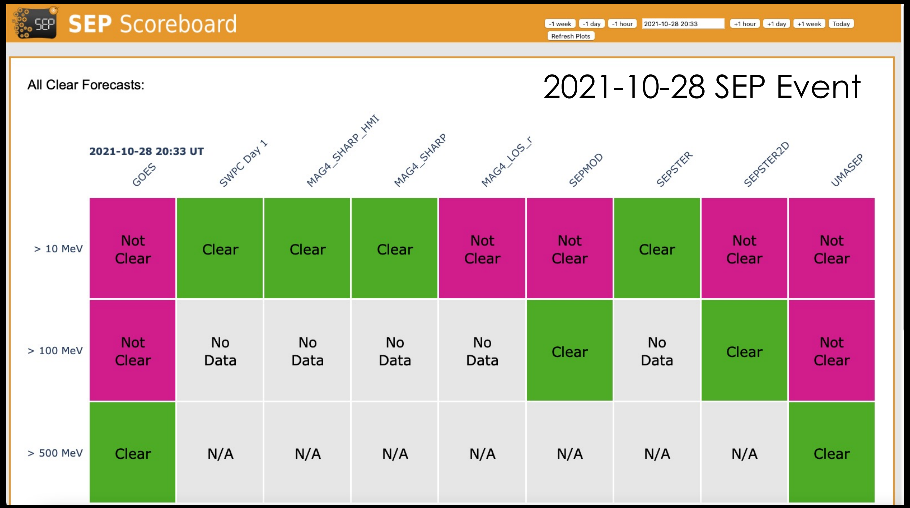
Figure 5. Fractional contribution to total BFO dose calculated in the Orion MPCV for the storm shelter crew configuration as a function of the minimum energy of the free-space SEP proton spectrum used in the transport and dose calculations. The shaded regions contain the fractional BFO dose contributions versus the minimum energies for the set of 65 historical SEP events.

Mertens, C. J., & Slaba, T. C. (2019). Characterization of solar energetic particle radiation dose to astronaut crew on deep-space exploration missions. *Space Weather*, *14* , 1650–1658. https://doi.org/10.1029/2019SW002363

THE ISEP PROJECT AND SEP SCOREBOARDS

- The SEP Scoreboards are running in real time and are being used by SRAG operators
    - All clear, Probability, Proton intensity
- Established SEP models have been integrated in the SEP Scoreboards (currently 6 models, ongoing effort)
- Work directly with modelers to expand, improve, and validate their models for operations in R2O2R effort





	GOES	SWPC Day 1	MAG4_SHARP_HMI	MAG4_SHARP	MAG4_LOS_r	SEPMOD	SEPSTER	SEPSTER2D	UMASEP
> 10 MeV	Not Clear	Clear	Clear	Clear	Not Clear	Not Clear	Clear	Not Clear	Not Clear
> 100 MeV	Not Clear	No Data	No Data	No Data	No Data	Clear	No Data	Clear	Not Clear
> 500 MeV	Clear	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Clear

^ All Clear SEP Scoreboard
< Peak intensity and time intensity profile scoreboard
https://ccmc.gsfc.nasa.gov/challenges/sep.php

SEP MODEL VALIDATION FRAMEWORK CONCEPT

ISEP PROJECT
SHINE CHALLENGE
EUROPEAN SWW
ISWAT H3-01

K. WHITMAN, H. BAIN, L. MAYS, P. QUINN, I. RICHARDSON, M. DIERCKXSENS

1. Collect a set of predictions from all SEP model types through a community effort (SHINE/ISWAT/ESWW)

2. Create a code (OpSEP) to derive equivalent quantities from observational data sets

3. Create a generalized and flexible framework to pair observations and predictions and validate for *science and operations*

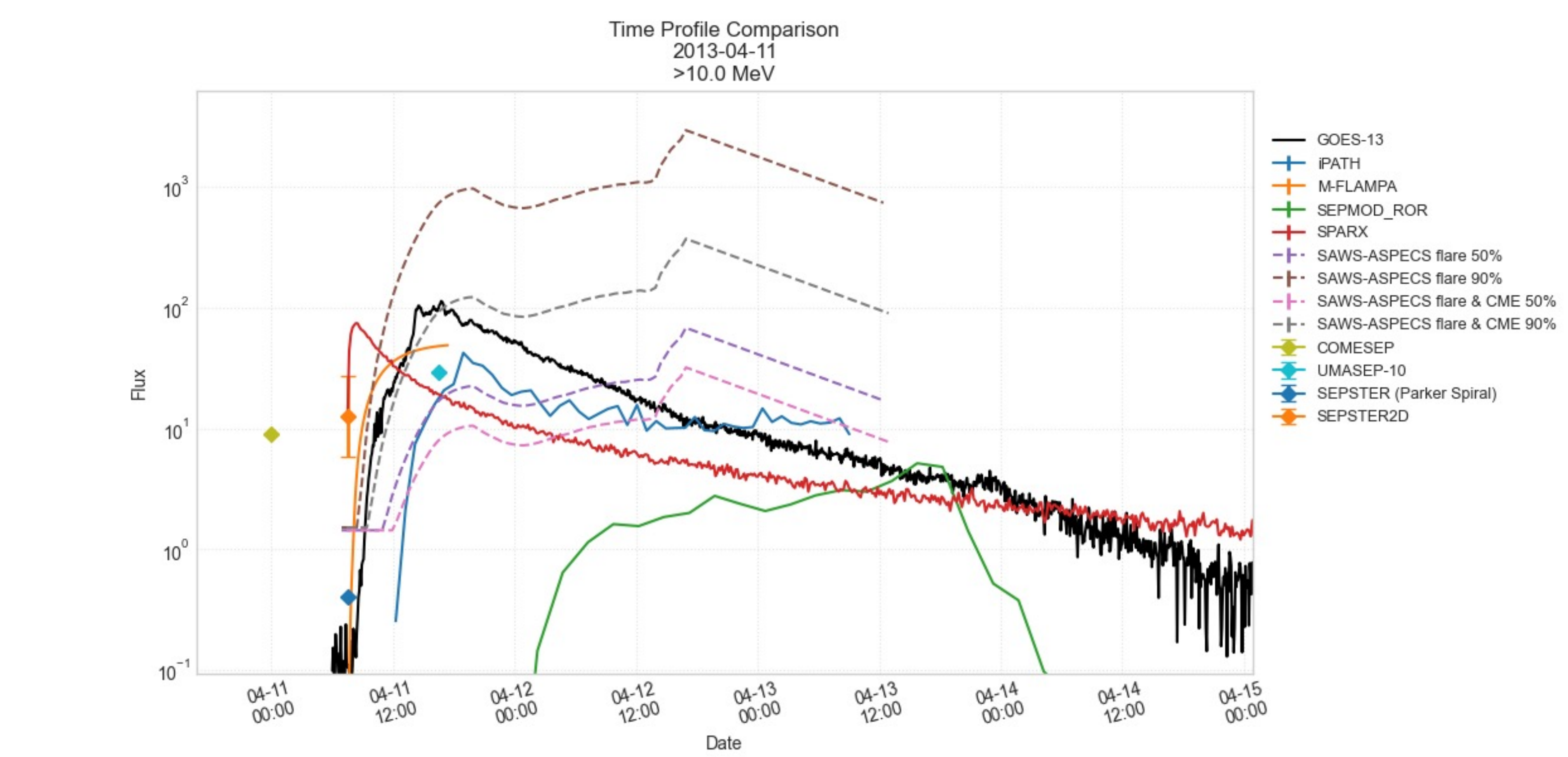
Supporting work:

- **Standardized Inputs:**
  - Provide forecasting-quality flare and CME inputs for model triggers
  - Derived observed suprathermal seed spectra to determine if useful for modelers (Maher Dayeh, SWRI)
- **Observations:**
  - Prepare observations and develop set of recommendations for best use of available data sets for validation
- **Synergistic with the SEP Scoreboard:**
  - Use CCMC SEP Scoreboard JSON file format as input and develop a pipeline directly from the Scoreboard into the validation code

SEP MODEL COMMUNITY VALIDATION EFFORT

PARTICIPATING MODELS:

- **ASPECS** (Papaioannou et. al.)
- **COMESEP** (Dierckxsens et al.)
- **HESPERIA REleASE** (Posner, Kuhl, Malandraki)
- **iPATH + ZEUS** (Li, Hu)
- **MAG4 SEP** (Falconer, Khazanov)
- **M-FLAMPA** (Sokolov, Zhao)
- **SEPMOD + ENLIL** (Luhmann)
- **SEPCaster** (iPATH + AWsoM) (Li, Jin)
- **SEPSTER** (Richardson, I.)
- **SEPSTER2D** (Bruno)
- **SPARX** (Marsh, Dalla, Swalwell)
- **STAT** (MAS + EPREM) (Linker, Schwadron)
- **UMASEP** (Núñez)



VALIDATION:

- Historical forecasts for a small selection of 10 SEP events
- SHINE 2022: Focus on forecasting for a small number of “non-events” to test for false alarms

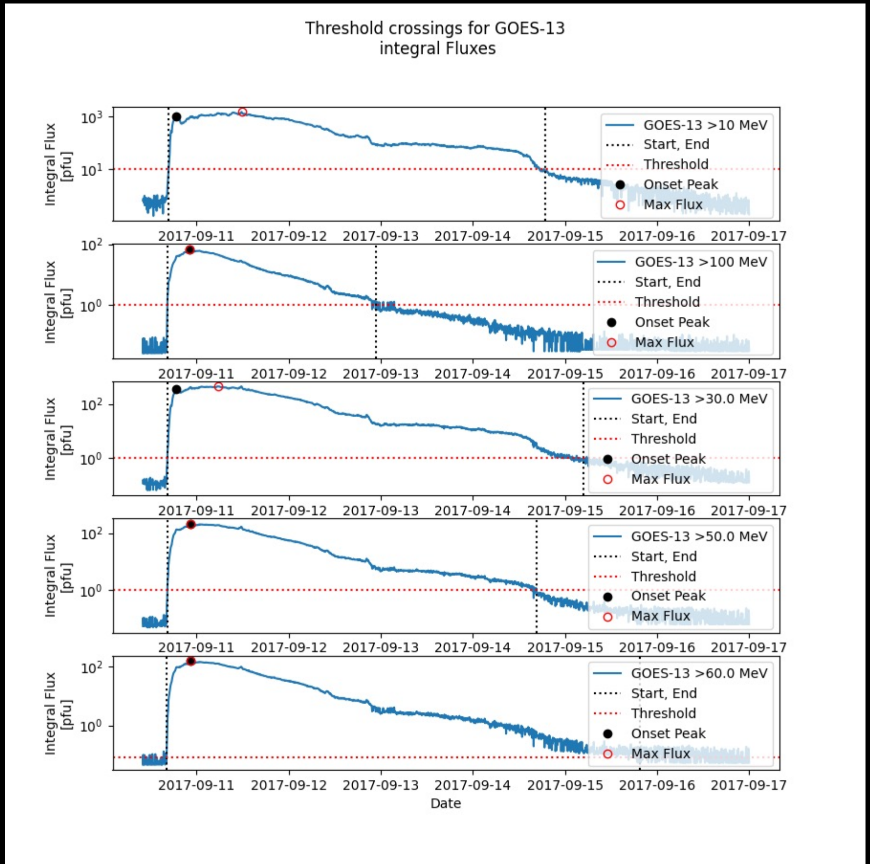
OPSEP CODE: CALCULATE QUANTITIES FROM TIME PROFILES (OBSERVATIONS OR MODELS)

THRESHOLDS:

- Operational thresholds >10 MeV exceeds 10 pfu, >100 MeV exceeds 1 pfu
- User-defined thresholds applied to integral or differential channels

QUANTITIES calculated by applying thresholds:

- **Start and End Times (Threshold crossing time)**
- **Onset Peak Flux:** the flux value at the location that the initial intensity rise turns over and increases more gradually or decreases
- **Time of Onset Peak**
- **Maximum Flux:** maximum flux between the start and end times
- **Time of Maximum Flux**
- **Duration**
- **Channel fluence:** for each channel a threshold was applied
- **Event fluence spectrum**



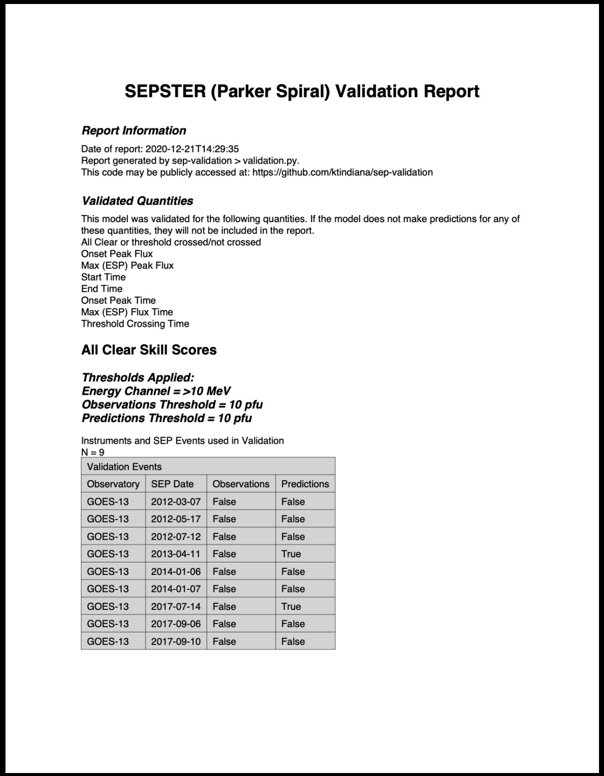
- **Native Data Sets:** GOES, SOHO/EPHIN, SEPEM, (STEREO and IMP-8 TBA)
- **User Input:** SEP Time profiles produced by models
- **Outputs JSON files in the format mirroring the SEP Scoreboard**

Available on github: https://github.com/ktindiana/operational-sep

SEP MODEL VALIDATION

- A validation framework is in development to validate SEP models
- Calculates metrics and plots for a wide variety of forecasted values
- SEP models often different by an order of magnitude, so worthwhile to improve forecasts despite imperfect data sets

Validated Forecasts To-Date
All Clear
Probability of occurrence
Threshold Crossing Time
Start Time
End Time
Onset Peak Flux
Onset Peak Time
Maximum Flux
Maximum Flux Time
Event-integrated Fluence
Overall Flux Time Profile



SEPSTER (Parker Spiral) Validation Report

Report Information

Date of report: 2020-12-21T14:29:35
Report generated by sep-validation > validation.py.
This code may be publicly accessed at: https://github.com/ktindiana/sep-validation

Validated Quantities

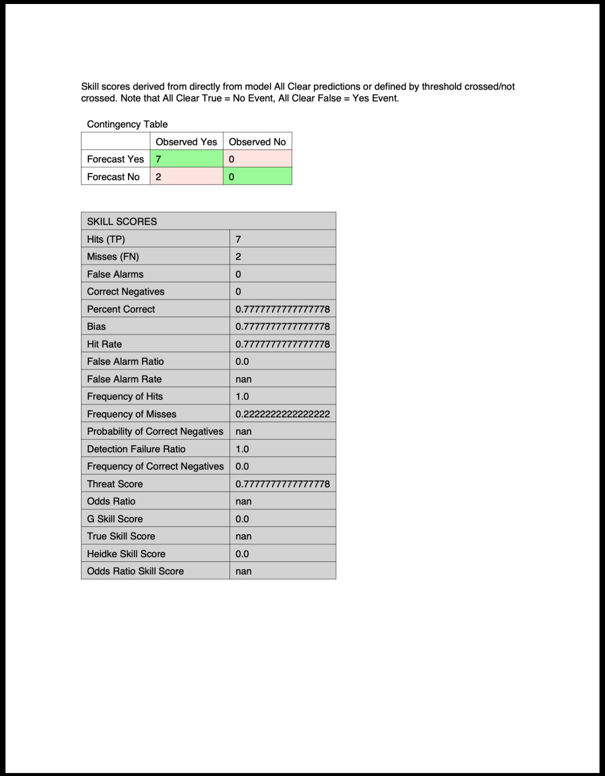
This model was validated for the following quantities. If the model does not make predictions for any of these quantities, they will not be included in the report.
All Clear or threshold crossed/not crossed
Onset Peak Flux
Max (ESP) Peak Flux
Start Time
End Time
Onset Peak Time
Max (ESP) Flux Time
Threshold Crossing Time

All Clear Skill Scores

Thresholds Applied:
Energy Channel = >10 MeV
Observations Threshold = 10 pfu
Predictions Threshold = 10 pfu

Instruments and SEP Events used in Validation
N = 9

Validation Events			
Observatory	SEP Date	Observations	Predictions
GOES-13	2012-03-07	False	False
GOES-13	2012-05-17	False	False
GOES-13	2012-07-12	False	False
GOES-13	2013-04-11	False	True
GOES-13	2014-01-06	False	False
GOES-13	2014-01-07	False	False
GOES-13	2017-07-14	False	True
GOES-13	2017-09-06	False	False
GOES-13	2017-09-10	False	False

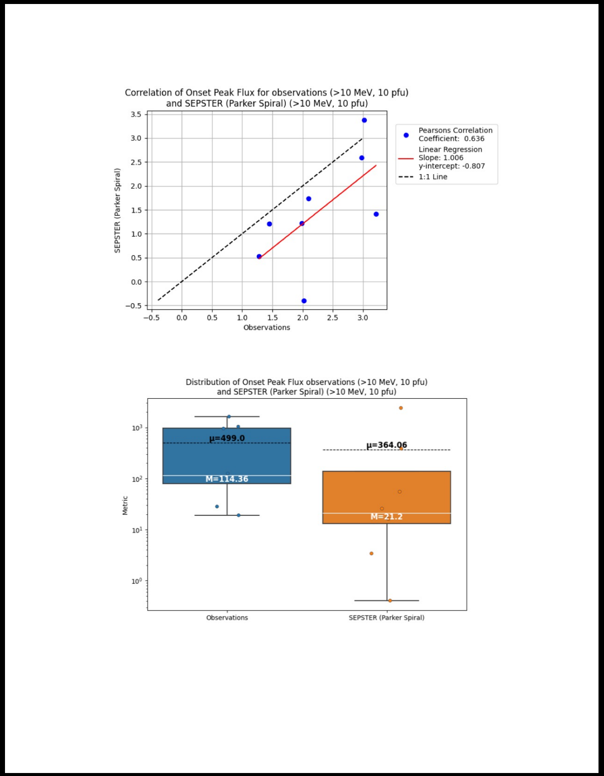


Skill scores derived from directly from model All Clear predictions or defined by threshold crossed/not crossed. Note that All Clear True = No Event, All Clear False = Yes Event.

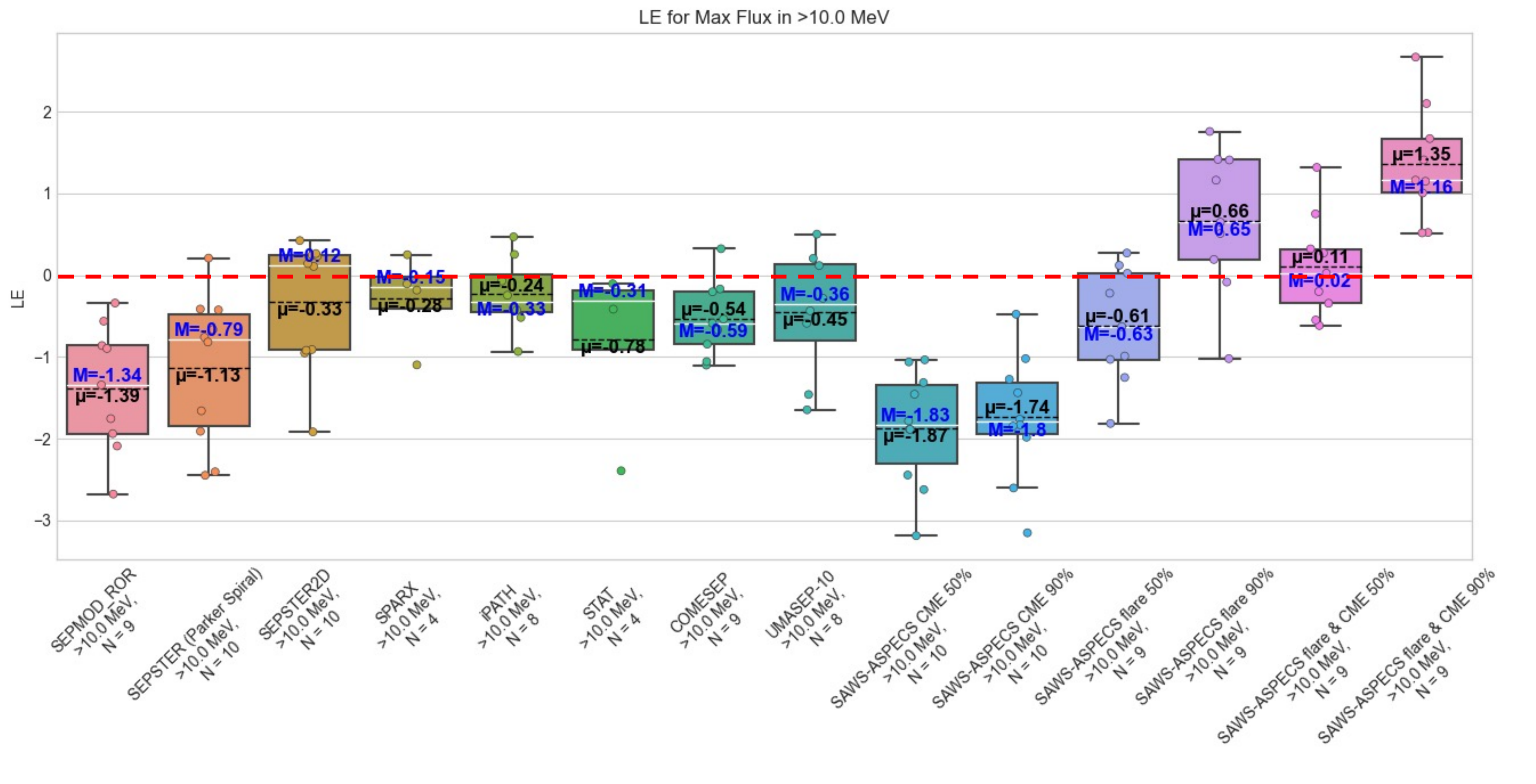
Contingency Table

	Observed Yes	Observed No
Forecast Yes	7	0
Forecast No	2	0

SKILL SCORES	
Hits (TP)	7
Misses (FN)	2
False Alarms	0
Correct Negatives	0
Percent Correct	0.7777777777777778
Bias	0.7777777777777778
Hit Rate	0.7777777777777778
False Alarm Ratio	0.0
False Alarm Rate	nan
Frequency of Hits	1.0
Frequency of Misses	0.2222222222222222
Probability of Correct Negatives	nan
Detection Failure Ratio	1.0
Frequency of Correct Negatives	0.0
Threat Score	0.7777777777777778
Odds Ratio	nan
G Skill Score	0.0
True Skill Score	nan
Heidke Skill Score	0.0
Odds Ratio Skill Score	nan

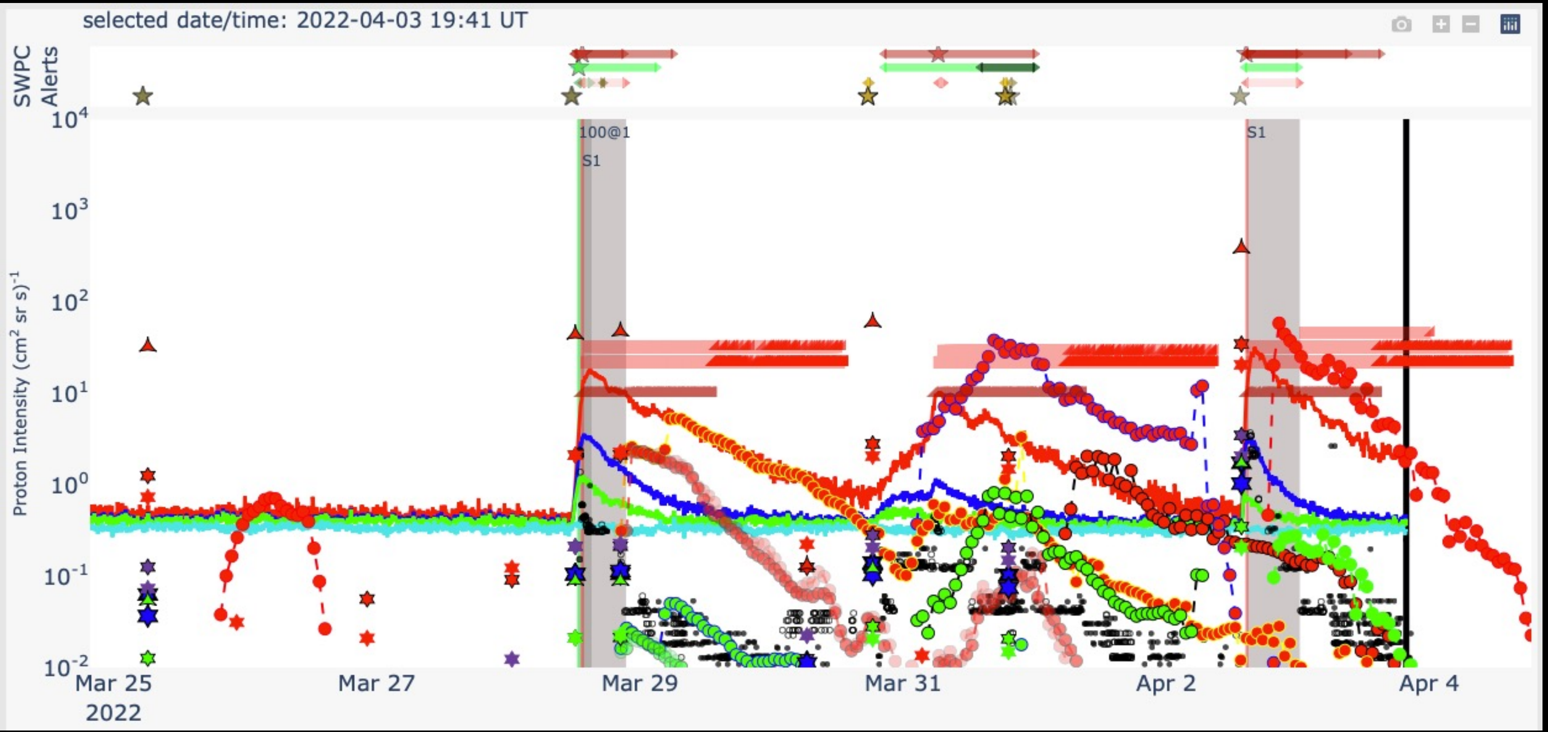


CROSS MODEL COMPARISONS



SEP SCOREBOARD VALIDATION EFFORT

- SRAG, CCMC, and M2M are collaborating through the ISEP project to validate the real time forecasts being produced on the SEP Scoreboard
- Validate models as they are run operationally - Advanced Warning Time, false alarms, and misses
- SEP Scoreboard models: HESPERIA/REleASE, MAG4, SEPSTER, SEPSTER2D, SEPMOD, UMASEP



Models developed for use in forecasting should be validated in an operational setting

ISEP efforts will validate all models in the SEP Scoreboard

VISION FOR THE VALIDATION CHALLENGE

First Phase – *quantitative comparisons with observations*

SHINE 2019 & ISWAT 2021
Collect forecasts for 10 Challenge SEP Events

Second Phase – *test for false alarms & correct negatives*

SHINE 2022
Collect forecasts for 14 periods when no SEP was observed

Third Phase – *Statistically significant metrics and cross-model comparisons*

Validation with statistically significant number of SEP events and non-events using standardized set of inputs and strict requirements

Final validation code product – *Integrated into CAMEL with assistance from CCMC*

- Third phase – ISWAT team will provide:
  - List of challenge events and non-events (~solar cycle 24)
  - CME and other input parameters
  - Time stamps after which no data may be used

- Incentive!!!!
- Perhaps a conference dedicated to presenting the final results?

BACK UP SLIDES

SPACE RADIATION ANALYSIS GROUP (SRAG)

- SRAG's mission is the protection of humans from space radiation
- Philosophy: As Low As Reasonably Achievable (ALARA)
  - *Accomplish mission goals while minimizing astronaut radiation dose*
- Establish human radiation exposure standards (career/acute)
- Operators support the Flight Control Team in Mission Control by monitoring the space weather and radiation environment and evaluating impact to crew
- Build and monitor a wide variety of vehicle-mounted and personal dosimeters
- Model the radiation environment in free space and within the vehicle
- Model and assess the biological risks due to radiation
- Develop flight rules that define requirements regarding radiation sources and actions in response to radiation events

OCHMO Radiation Standards

Astronaut's total career effective radiation dose (In 3001, Vol 1 Rev B)

600 mSv

Universal for all ages and sexes, 3% mean risk of cancer mortality, effective dose calculated using 35-year-old female

An individual astronaut's total career effective radiation dose due to space flight radiation exposure shall be less than 600 mSv.

Galactic Cosmic Radiation (GCR) (only under consideration) - achievable with ~10g/cm^2 Al

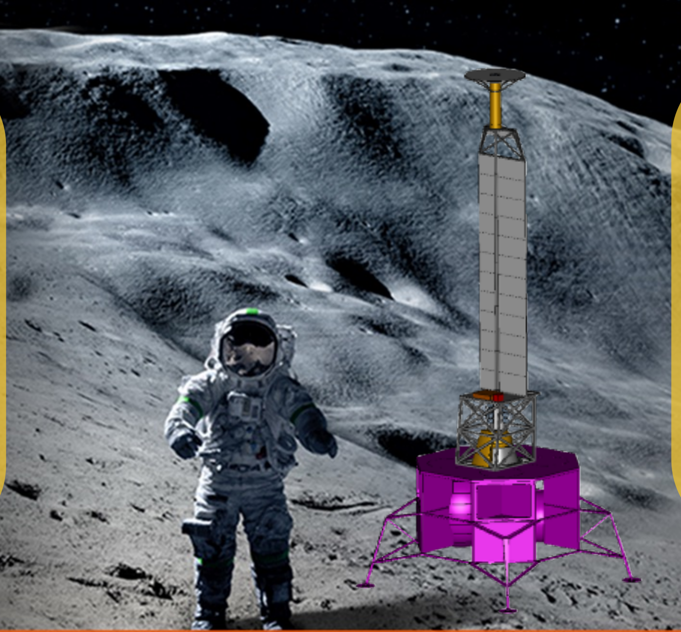
For missions beyond low Earth orbit, vehicles and habitat systems shall provide sufficient protection to reduce exposure from galactic cosmic radiation (GCR) by 15% compared with free space such that the effective dose from GCR remains below 1.3 mSv/day for systems in free space and below 0.8 mSv/day for systems on planetary surfaces.

250 mSv

20 mSv

Solar Particle Event (SPE)

The program shall protect crewmembers from exposure to the Design Reference Solar Particle Event (SPE) Environment Proton Energy Spectrum (sum of the October 1989 events) to less than an effective dose of 250 mSv).



Nuclear Technologies

Radiological exposure from nuclear technologies emitting ionizing radiation (e.g., radioisotope power systems, fission reactors, etc.) to crew members shall be less than an effective dose of 20 mSv per mission year (prorated/extrapolated to mission durations).

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SEP MODEL INPUTS

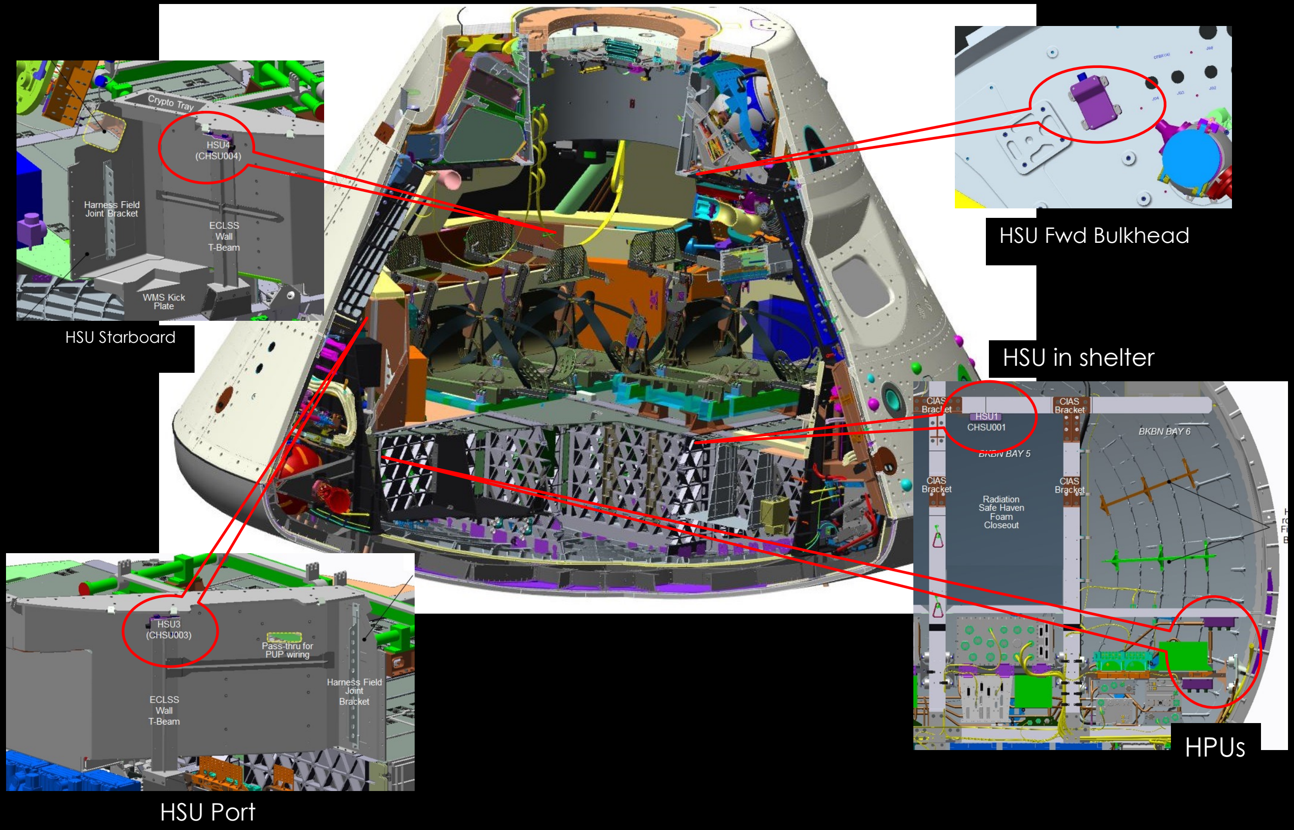
Table 10: Observational measurements used as inputs into SEP models.

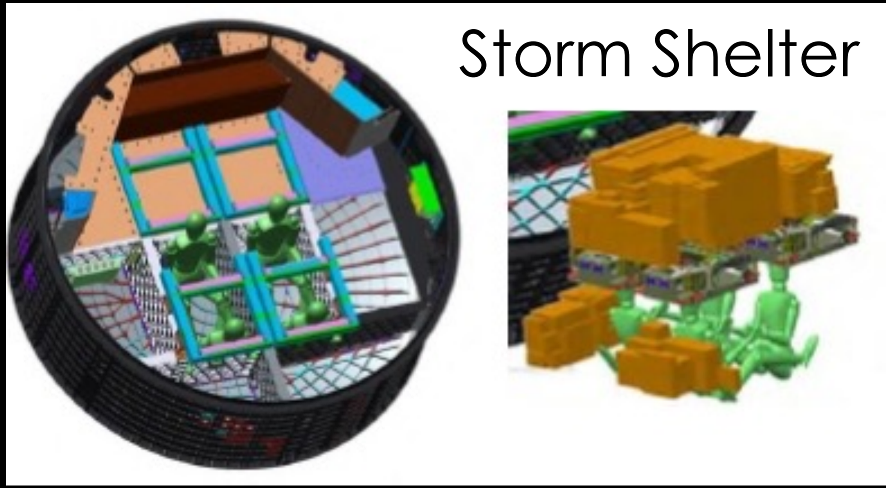
Model	Type	Magnetograms	Optical Imaging	EUV Imaging	Soft X-ray Intensity	Ground-based Radio	Space-based Radio	Coronagraph	Solar Wind (n,T,p,v)	Suprathermal Particles	Energetic Protons	Energetic Electrons	Neutron Monitors
ADEPT	Empirical										x		
AFRL PPS	Empirical		x		x	x							
Aminalragia-Giamini model	ML			x	x								
AMPS	Physics-based	x		x				x					
Boubrahimi model	ML				x						x		
COMESEP SEPForecast	Emp. & Physics			x	x			x					x
EPREM	Physics-based	x		x				x		x			
ESPERTA	Emp. & ML			x	x		x				x		
FORSPEF	Empirical	x	x		x		x	x					
GSU	ML	x											
iPATH	Physics-based	x		x				x	x	x			
Lavasa Model	ML		x		x			x					
MAG4	Empirical	x	x		x								
MagPy	Empirical	x	x		x								
MEMPSEP	ML	x		x	x		x	x	x	x	x	x	
M-FLAMPA	Physics-based	x		x				x					
PARADISE	Physics-based	x		x				x					
PCA model	Empirical				x			x					
PROTONS	Empirical				x	x							
REleASE	Empirical											x	
Sadykov's Model	ML	x			x	x					x		
SAWS-ASPECS	Empirical	x	x		x			x			x	x	x
SEPCaster	Physics-based	x		x				x	x				
SEPMOD	Physics-based	x		x				x					
SEPSTER	Empirical			x				x	x				
SEPSTER2D	Empirical			x				x	x				
SMARP Model	ML	x											
SOLPENCO	Physics-based			x				x					
SOLPENCO(2)	Physics-based			x				x	x		x		
South African model	Physics-based			x	x			x					
SPARX	Physics-based			x	x								
SPREAdFAST	Physics-based	x		x				x		x	x		
SPRINTS	ML	x		x	x						x		
STAT	Physics-based	x		x				x		x			
UMASEP	Empirical				x	x					x		
Zhang model	Physics-based	x		x				x	x				
Total		19	6	21	18	4	3	21	7	5	10	3	2

- SEP models make use of a wide variety of observational inputs
- In some cases, models have been developed, but cannot be run in real time or have delayed run times due to lack of operational support for the required data streams
  - Space-based radio
  - Coronagraphs (latency and cadence delays)
  - Manual calculation of CME parameters
- Energetic electrons are a valuable NOT All Clear indicator

Whitman et al. (2022), *Review of Solar Energetic Particle Models*, submitted to ASR

SHIELDING AND SHELTER





SEP DOSE IN DEEP SPACE – INSIDE THE VEHICLE

- For the nominal seated configuration:
  - >99% of the total BFO dose comes from >10 MeV protons
  - Total BFO dose from these SEP events extends from 54% to 95% for >100 MeV protons
  - Average and median contributions to BFO dose from >500 MeV protons is 3% - 4%, but the spread in dose contributions is quite large.

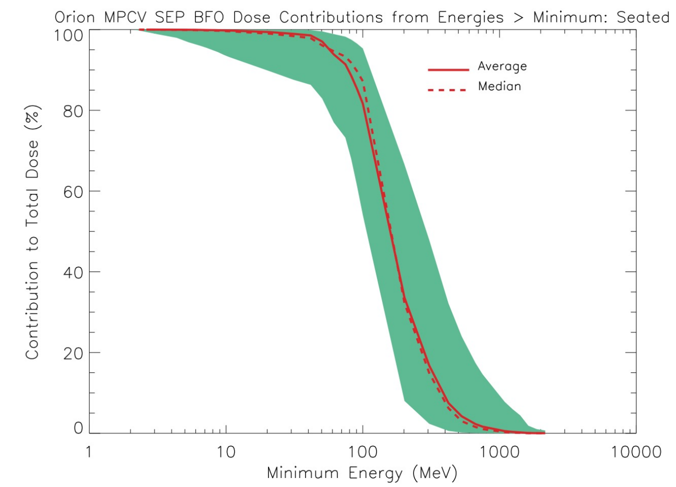
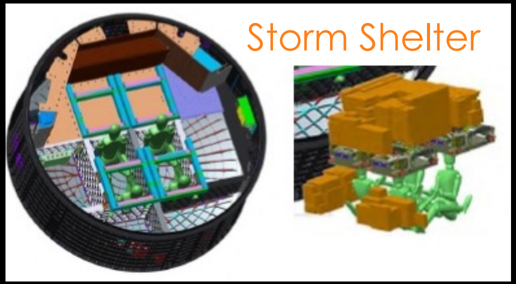


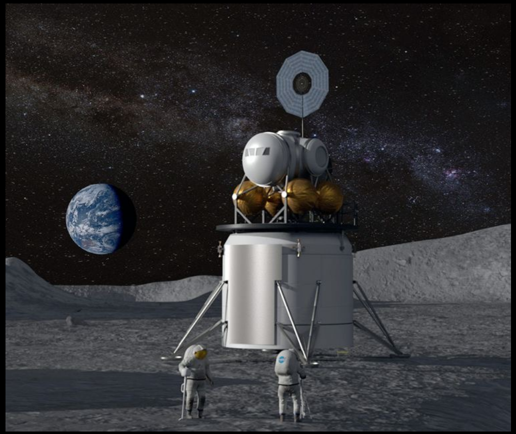
Figure 4. Fractional contribution to total BFO dose calculated in the Orion MPCV for the seated crew configuration as a function of the minimum energy of the free-space SEP proton spectrum used in the transport and dose calculations. The shaded regions contain the fractional BFO dose contributions versus cutoff energies for the set of 65 historical SEP events.

Mertens, C. J., & Slaba, T. C. (2019). Characterization of solar energetic particle radiation dose to astronaut crew on deep-space exploration missions. *Space Weather*, *14* , 1650–1658. https://doi.org/10.1029/2019SW002363

OPERATIONAL RELEVANCE OF SEP FORECASTS

- Operational relevance stated here is presented from the perspective of SRAG for space radiation impacts to humans
- Limited SEP impact on the ISS in Low Earth Orbit due to the protection of the Earth's magnetosphere
- Astronauts onboard Artemis will be able to build a shelter within 30 minutes
- Astronauts performing a lunar EVA are required to stay within a 1-hour radius from the lander (life support systems requirement)





- ➢ Astronauts can respond to an SEP event within a 30 – 60-minute timeframe. Therefore, regardless of All Clear status, if an eruptive event has not yet occurred (flare, CME), it is advantageous to carry out planned EVAs or other important tasks as the task could be completed prior to an eruption. If an SEP event does occur, astronauts can respond quickly.
- ➢ Two types of useful SEP forecasts:
  - ➢ All Clear or probability prior to an eruption (issued every 6, 12, 24, 48, etc hours)
  - ➢ All Clear and forecasts of all kinds (timing, peak, time profile, fluence) immediately following an eruption to enable quick response

SPACE WEATHER FORECASTING AND SEP MODELING

- NOAA SWPC provides NASA with space weather forecasting services, and this will continue for Artemis
- Additional operational tools and support will be utilized for fast response to Mission Control
    - Support for operational space weather models provided by the new Moon to Mars Space Weather Analysis Office (M2M) at NASA Goddard
    - CCMC's SEP Scoreboards have been developed in a collaborative effort between SRAG, Moon to Mars Space Weather Analysis Office (M2M), and the Community Coordinated Modeling Center (CCMC) called the Integrated Solar Energetic Proton Event Alert/Warning System (ISEP) project
        - A suite of SEP models have been assembled into a real-time framework that includes both US and ESA/EU components

SEP DOSE IN DEEP SPACE – DOSE EFFECTS AND LIMITS

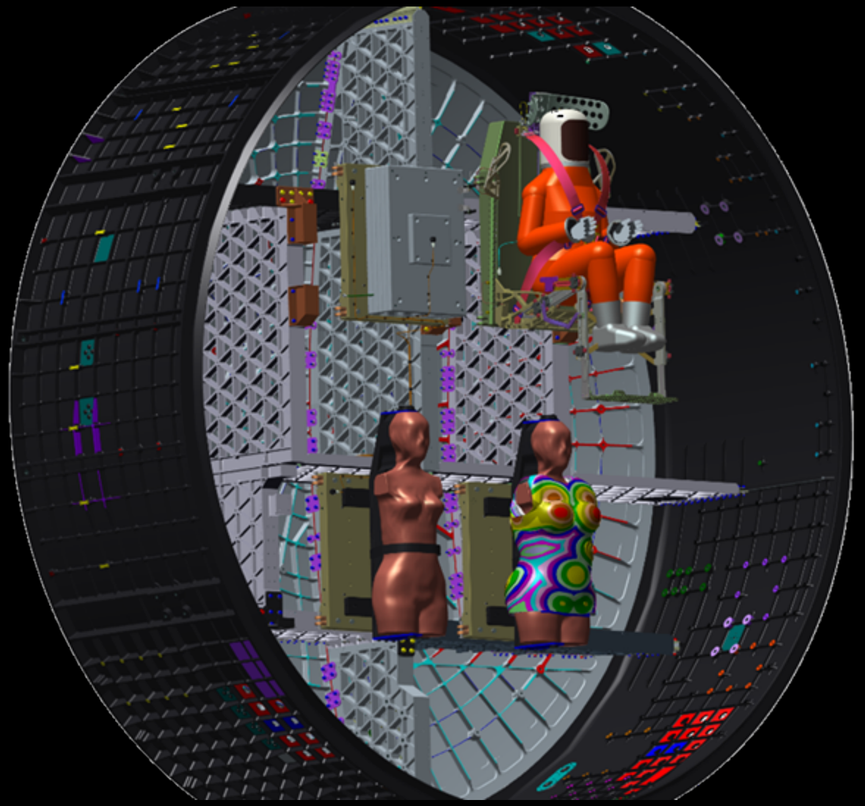
- The shielding design of the Orion vehicle is sufficient to protect in-flight astronauts against acute radiation syndromes for all SEP events encountered during the space age.
- Acute biological responses to SEP exposures are possible for astronauts in less shielded environments, if no further mitigation strategies are implemented.
- Large SEP events can significantly increase the risk of cancer death and contribute significantly toward reaching NASA's permissible exposure limits.
- ALARA and the ability to act quickly requires real-time measurements and nowcast/forecast models of the space radiation environment.

Mertens, C. J., & Slaba, T. C. (2019). Characterization of solar energetic particle radiation dose to astronaut crew on deep-space exploration missions. *Space Weather*, *14* , 1650–1658.
https://doi.org/10.1029/2019SW002363

ARTEMIS I

- The uncrewed Artemis I mission will act as a test bed for our technologies
  - Dosimeters mounted throughout the vehicle
  - Extensive radiation measurements inside two female anthropomorphic phantom torsos
  - A radiation-protection vest prototype

- Opportunity for SRAG, SWPC, and M2M to test the operational strategies in place to forecast and mitigate SEP events
  - 24/7 mission support
  - Office-to-office communications
  - ARRT
  - SEP Scoreboards



KEY OBSERVATIONS FOR SPACE WEATHER FORECASTING

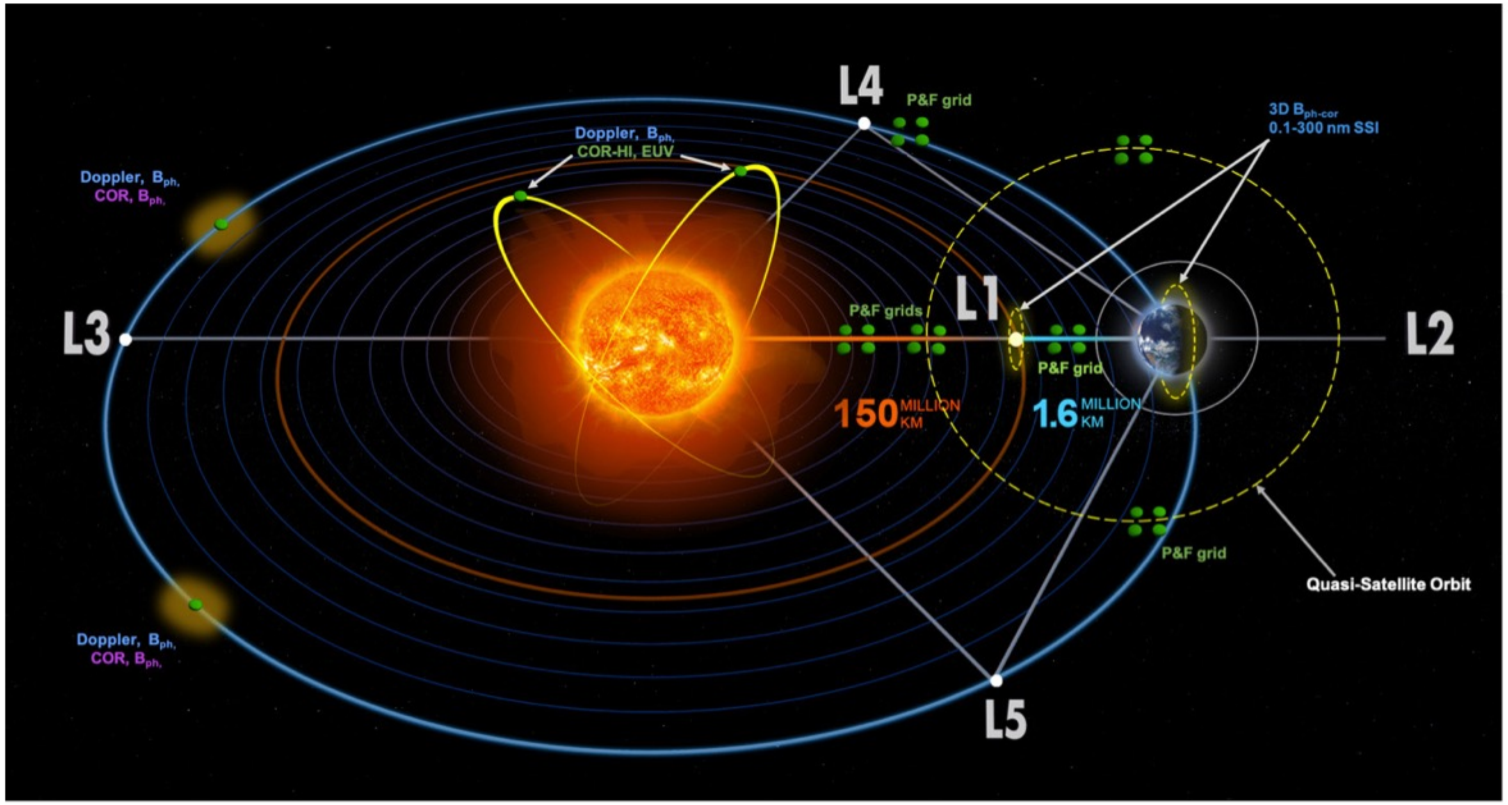


Figure 6-2. Visual representation of the locations and types of measurements that can lead to closure for several SWx research and forecasting issues. Details are provided in Table 6-4 and Section 5.

- Image Credit: *Space Weather Science and Observation Gap Analysis for the National Aeronautics and Space Administration (NASA).* (Vourlidas et al. 2021) https://science.nasa.gov/science-pink/s3fs-public/atoms/files/GapAnalysisReport_full_final.pdf)

- New observations to prioritize in near future for SEP All Clear forecasting:
  - High cadence coronagraphs at L1, L4, L5
  - Magnetograms, EUV, magnetic fields, & particles at L4 and L5
- Near sun particle and mag field measurements or real time support for data from existing experiments (PSP, SO)

SPACE FLIGHT HUMAN SYSTEM STANDARDS – NASA-STD-3001, VOL 1 CREW CAREER PERMISSIBLE EXPOSURE LIMIT FOR SPACE FLIGHT RADIATION

After iterating with the NASEM committee, the following standard was proposed.

4.2.10 Space Flight Radiation Permissible Exposure Limit

An individual astronaut's total career effective radiation dose due to spaceflight radiation exposure shall be less than 600 mSv. This limit is universal for all ages and sexes.

Rationale [The total career dose limit is based on ensuring all astronauts (inclusive of all ages and sexes) remain below 3% mean risk of cancer mortality (REID) above the non-exposed baseline mean. Individual astronaut career dose includes all past spaceflight radiation exposures, plus the projected exposure for an upcoming mission.]

The 600 mSv is based on a 3% mean REID calculation for a 35-year-old female utilizing the operational NSCR2012 model with the NASA Q, never smoker parameters.

Note the 600 mSv effective dose standard is for post mission cancer. Even though the evidence does not support a limit for cardiovascular and CNS, the proposed standard is protective for Cardiovascular and CNS effects.

Based on current understanding and state of knowledge, exposure limits for

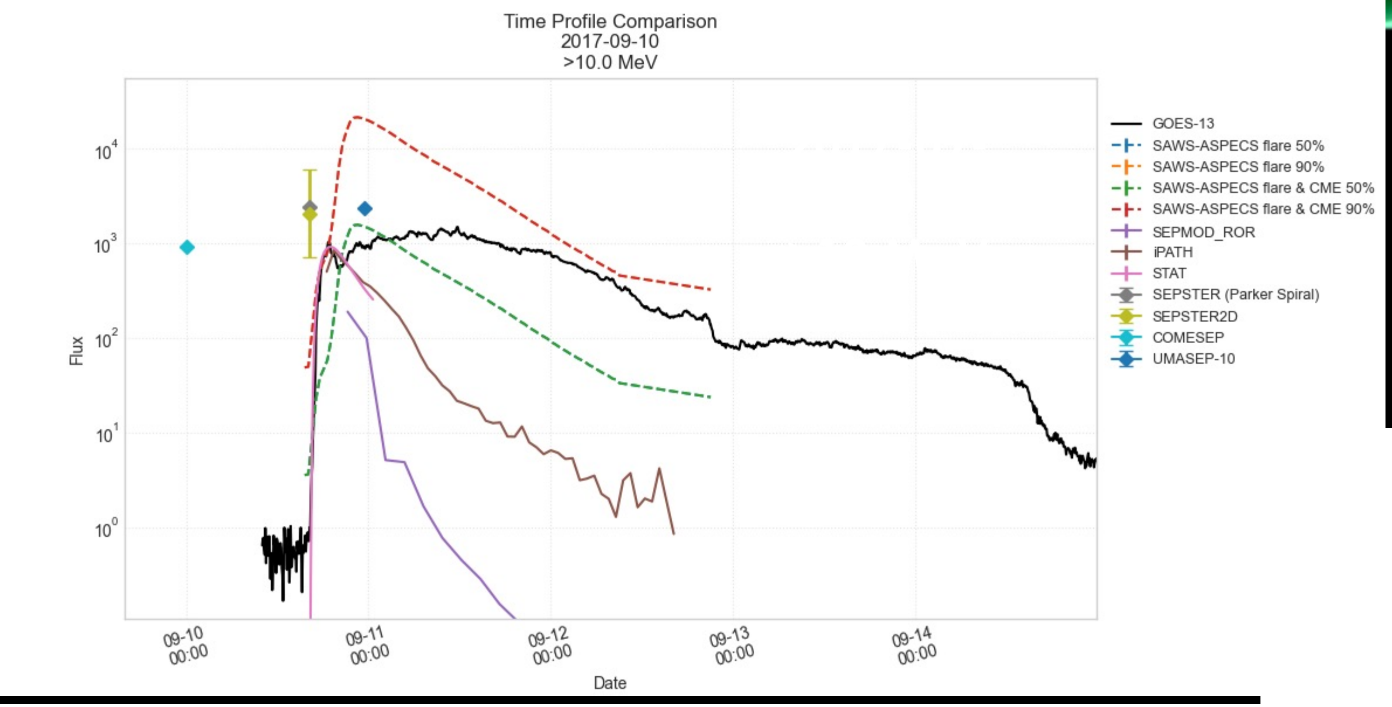
- cardiovascular disease is <500 mGy equivalent
- central nervous system (CNS) effects is < 500 mGy-Eq
  - and < 100 mGy for z > 10.

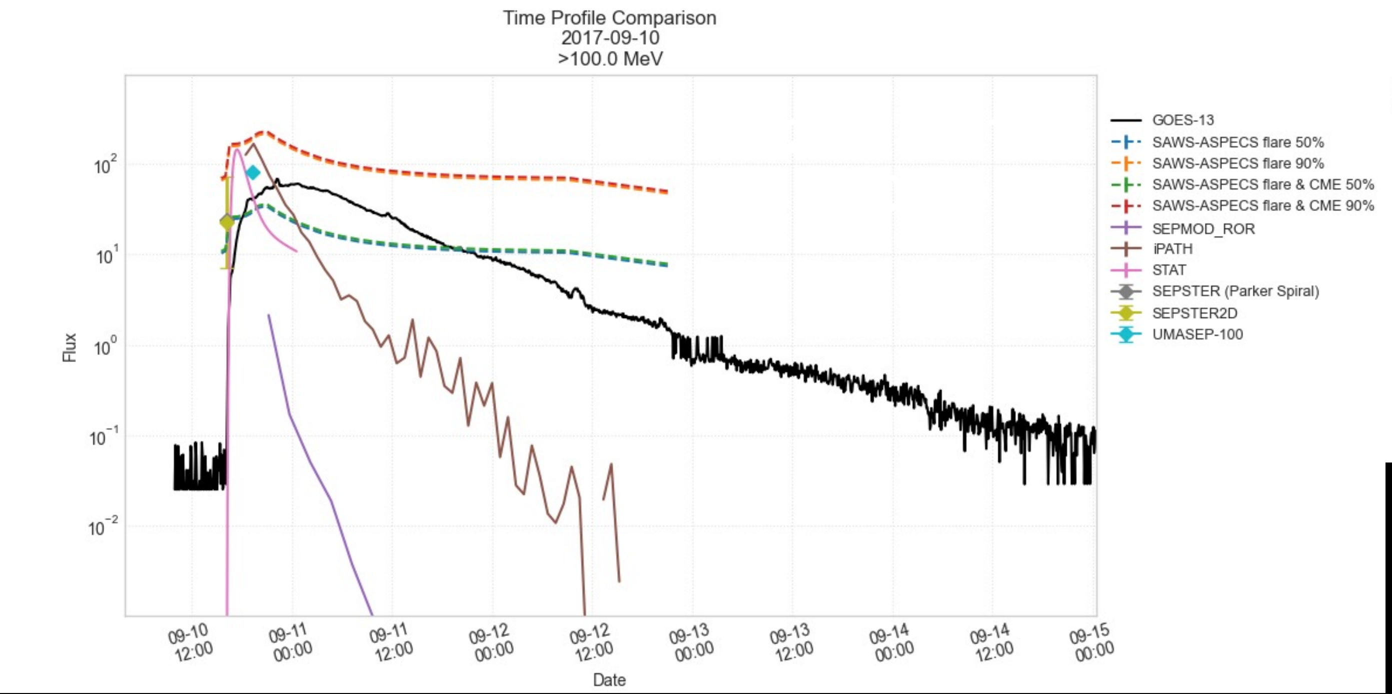
600 mSv is equivalent to

- 380 mGy-Eq for the heart
- 231 mGy for CNS organ (z < 10)
  - 6 mGy for CNS organs for Z $\geq$ 10.

NASA will continue to assess these risks and will make the appropriate updates as more knowledge is obtained.

Participating Models





2017-09-10
REleASE 28.2 – 50.1 MeV
SOHO/EPHIN 25 – 40.9 MeV