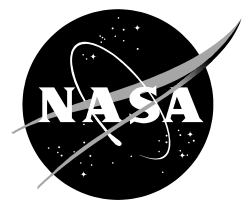


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A Multi-Source Calibrated GOES Dataset And Solar Radiation Environment Model Update

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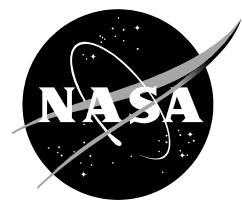
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This report is available in electronic form at

Abstract

The ESP-PSYCHIC model is the present standard by European and US space agencies for mission design limits on solar energetic proton (SEP) fluences, which gives predictions of cumulative fluences, the highest fluences, and peak fluxes over a user-specified mission duration as a function of confidence level. Additional SEP data and new methodologies have led to the advancement of solar radiation environment models in several directions, including the explicit treatment of event durations and waiting times in between events, the occurrence of SEP events during quieter periods (e.g. solar minimum), and extending model coverage up to much higher energies. As most current state-of-the-art spacecraft are designed with thick shielding, the high energy protons are particularly relevant to radiation analysis for spacecraft reliability and crew protection during the planned exploration missions. However, the extension to higher energies of most previous models relied on extrapolation with functional fittings of historical events, which contains implicit uncertainties as the characteristics of each event are unique. In this work we reported a multi-source calibrated GOES dataset of past 3 solar cycles and used it to update the worst fluence model with energy coverage of 10-1000 MeV through the ESP-PSYCHIC approach. Both the low energy and high energy sections of the predicted spectrum are compared with previous models and historical large events. The dataset can be further applied with more advanced methodologies to develop more models for use by spacecraft designers and mission operators.

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ACRONYMS

EPEAD	Energetic Proton, Electron and Alpha Detectors
EPS	Energetic Particle Sensors
ESP	Emission of Solar Protons
GCR	Galactic Cosmic Rays
GLE	Ground Level Enhancement
GME	Goddard Medium Energy
GOES	Geostationary Operational Environmental Satellite
IMP	Interplanetary Monitoring Platform
JPL	Jet Propulsion Laboratory
MBF	Modified Band Function
MPCV	Multiple Purpose Crew Vehicle
MSSREM	Mission Specific Solar Radiation Environment
MSU	Moscow State University
NOAA	National Oceanographic and Atmospheric Administration
PAMELA	Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics
PSYCHIC	Prediction of Solar particle Yields for Characterizing Integrated Circuits
SAPPHIRE	Solar Accumulated and Peak Proton and Heavy Ion Radiation Environment
SEP	Solar Energetic Particle
SEPEM	Solar Energetic Particle Environment Modelling
SPE	Solar Particle Events
SPENVIS	SPace ENVironment Information System
SSN	Sunspot Numbers
UTU	University of Turku
WASPE	Web App for Solar Particle Events

1. Introduction

Bursts of Solar Energetic Particles (SEP) can be suddenly released from the Sun along with electric and magnetic fields through coronal mass ejections (CME) and solar flares. Under certain conditions, these fast-moving particles can further accelerate themselves by shock waves and consolidate other sources in interplanetary space to form large scale Solar Particle Events (SPE) that impact extensive portion of heliosphere (Reames, 2013). If the Earth is in the path of these large volume of SEP and the embedded electromagnetic fields, its magnetosphere can be deformed and many essential satellites circuiting around it are prone to disruptions such as displacement damage, single-event upsets, and total dose effects (Feynman & Gabriel, 2000). They can even impact the ground electricity grid network and aviation routes passing through the polar regions. These particles are particularly of concern to space exploration missions beyond the protection of the Earth's magnetic field such as the planned trips to the Moon and Mars, and significant efforts are undergone in spacecraft design, mission plan, and scientific research to mitigate their risks to the electronic systems and crew (Xapsos, 2019).

Although physical shielding can prevent most of these energetic particles from penetrating into the spacecraft, the space system design needs to balance the trade-offs between risk and cost in a systematical way. Accurate solar radiation environment models are therefore essential for developing reliable and cost-effective new space technologies. It was shown that the energy release due to SPE is consistent with the dynamics of a self-organized criticality system such as earthquakes, avalanches, and rainfall (Xapsos, 2006), and the models to describe solar radiation environment are generally assumed to be stochastic in nature. They could provide predictions of cumulative fluences of a mission, highest fluences or peak fluxes resulting from a single event to be seen over a user-specified mission duration as a function of confidence level, etc. Past models of SPE occurrences include the King model (King, 1974), the Jet Propulsion Laboratory (JPL) model (Feynman et al., 1990; 1993; 2002), the Emission of Solar Protons (ESP) model (Xapsos et al., 1998; 1999), and Moscow State University (MSU) model (Nymmik, 1999; 2007; 2011). ESP was expanded to also include models of the cumulative fluence environment extrapolated from the distribution of yearly solar proton fluences and was later renamed as the PSYCHIC (Prediction of Solar particle Yields for Characterizing Integrated Circuits) model (Xapsos et al., 2000; 2004; 2007). The ESP-PSYCHIC model is the present standard for long-term SEP fluences as specified in the relevant documents from European and US space agencies (ECSS, 2020; SWORM, 2018).

With additional SEP data and new methodologies, the modeling of solar radiation environment advances recently in several directions. The first group of works emphasize the non-point-like property of SPEs, by considering event durations and waiting times between events (Jun et al., 2007; Jiggins et al., 2012). The second category of models follow the MSU modeling approach, i.e., assuming the event frequency is solar cycle dependent based on sunspot (Wolf) number rather than invariant over seven solar active years per cycle (Kim et al., 2009; Robinson et al., 2019). This allows periods of high solar activity (solar maximum) with quieter periods

(solar minimum) to be treated nonhomogeneously and all time can be considered in mission planning and analysis. The third direction leads to models of predicted spectra extended to much higher energies than early models, such as the Solar Accumulated and Peak Proton and Heavy Ion Radiation Environment (SAPPHIRE) Model (Jiggins et al., 2018), the Mission Specific Solar Radiation Environment Model (MSSREM) (Robinson et al., 2019), and the University of Turku (UTU) model (Raukunen et al., 2018), all using the Band function formalism (Band et al., 1993) to extrapolate spectra to reach 1 GeV. Extending the solar radiation environment models to higher energies are important for spacecraft reliability analysis and astronaut protection, as most current state-of-the-art spacecraft are designed with thick shielding (e.g., the Orion Multiple Purpose Crew Vehicle (MPCV) (Mertens et al., 2018)) and only the high energy protons are relevant to radiation exposure analysis inside vehicles (Hu et al., 2020).

The accuracy of these statistic models is highly relied upon the dataset of proton measurement that was available at the time of development. For example, the PSYCHIC model is considered as a significant improvement of ESP model (Xapsos et al., 2004). Though both models used data of IMP-3, -4, -5, and -8 satellites and GOES-5, -6, and -7 covering the time period from 1966 to 2001, the ESP model treated data from different instruments independently, and the model was limited with an upper energy bound of >100 MeV and had to use spectra of several large SPEs to extrapolate to >300 MeV (Xapsos et al., 1999). But after combining the IMP-8 GME data and GOES-6 and -7 data into an integrated data set, the highest energy of PSYCHIC model extended to 327 MeV (Xapsos et al., 2004). For this reason, the developers of recent models such as SAPPHIRE and MSSREM exerted significant efforts to prepare high quality proton datasets (Jiggins et al., 2012, 2018; Robinson et al., 2019). In this work, we reported a multi-source calibrated GOES proton data covering the period of 1986-2019 with highest energy of 1 GeV, and presented an updated worst case fluence model through the ESP-PSYCHIC approach. The paper is structured in 4 further sections:

- GOES proton data calibration (Sect. 2);
- methods to prepare the data (Sect. 3);
- modeling methodology, statistical distributions, results, and comparison with previous models and historical large events (Sect. 4);
- concluding remarks (Sect. 5).

2. Multi-source calibration of GOES proton measurement

For several decades, the Geostationary Operational Environmental Satellites (GOES) series provide both real-time and historical data for radiation exposure estimation and solar proton radiation environment modeling. Recently, several groups conducted calibration studies that significantly reduced the uncertainties on the response of GOES proton detectors, thus improving the reliability of the spectral observations of solar energetic particle events. In the work of Sandberg et al. (2014), the Energetic Particle Sensors (EPS) measurements of GOES 5, 7, 8, and 11 were compared with NASA IMP-8/Goddard Medium Energy (GME) experiment data set, and the proton energies derived for the P2–P7 channels were significantly lower than the nominal energies through ground proton beam calibration (Onsager et al., 1996). In a later work by Bruno (2017), using the high-energy particle measurements of the Payload for Antimatter

Matter Exploration and Light-nuclei Astrophysics (PAMELA), a set of effective energies were determined for the proton channels of the P6 and P7 and the High Energy Proton and Alpha Detector (HEPAD) P8–P11 sensors on board GOES 13 and 15. In addition, Raukunen et al. (2020) reported a comprehensive bowtie analysis of the HEPAD proton channel energy responses as measured with energetic proton beams.

We also reported a calibration study of GOES proton data by using models of Ground Level Enhancement (GLE) events based on measurement of multiple satellites and ground neutron monitors (Hu & Semones, 2022). Two sets of GLE models were applied as references; One is the Band function form (Tylka & Dietrich, 2009), assuming a constant background proton flux before and after an event, and the other is the Modified Band Function (MBF) form, assuming a variant background flux through each GLE and a revised neutron-monitor yield function (Koldobskiy et al., 2021). Comparing with event-integrated fluences of the GLEs recorded by GOES 6, 8, 10, 11, 13, and 15, we obtained two sets of effective energies for each proton channel of EPS and HEPAD onboard these satellites. Except for GOES 6, the energies obtained from uncorrected data and corrected data through the Zwickl algorithm (Rodriguez et al., 2017) have minor differences (Hu & Semones, 2022), which has been demonstrated in the calibration work using the PAMELA measurements (Bruno, 2017). Like this work, directly using the uncorrected flux, we showed the integral channel P11 can be treated as a differential channel at about 1 GeV. Because most proton channels, except for P4 of GOES 6, of both EPS and HEPAD functioned properly in all these missions during the period of 1986-2019, a contiguous and uniform dataset of solar proton fluxes encompassing energies from several MeV to about 1 GeV can be developed for the past 3 solar cycles.

The quality of such a long-range dataset not only depends on the energy coverage, but also the consistency of the measurements as compared with other observations of high fidelity. The datasets developed for SAPPHIRE and MSSREM models (Jiggins et al., 2012, 2018; Robinson et al., 2019) were based on cross-calibration with IMP-8 GME measurement, which is known to suffer saturation effects during some of the largest events, and the sporadic invalid values had to be carefully detected and filled with other measurements such as those of GOES 7 (Xapsos et al., 2004). In addition, our recent study indicated the IMP-8 GME instrument may have experienced performance degradation along its service time from 1973 to 2001 (Hu & Semones, 2022). To verify the effective energies obtained by calibrating with GLE models, we compared the spectra of 4 SPEs not used in our list of GLEs but recorded by GOES-10, -11, -13 and 15, with PAMELA measurement, bowtie analysis, and GOES-16 data analysis (Hu & Semones, 2022). Of the two sets of energies, we found the spectra generated with MBF energies (Table 1) are more consistent with those from these multiple sources as well as the calibration work of Bruno (2017). The PAMELA data are distinctive in situ measurements from those of GOES series, the bowtie analysis and GOES-16 energies are based on different ground calibrations, and the GLE models are derived from the analysis of the data of multiple satellites and ground neutron monitors, therefore, the effective energies we obtained for the proton channels of GOES 6-15 can be regarded as a set of multi-source calibrated energies (Table 1).

Table 1. Effective energies of proton channels of GOES obtained by calibration with MBF models (Hu & Semones, 2022). P4 data of GOES 6 were not used due to erratic measurement during the mission (Mottl & Nymmik, 2007).

Satellites	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
GOES 6	4.7	8.3		39.1	128.5	274.2	336.1	402.3	837.5	887.5
GOES 8	7.3	10.5	16.3	40.9	116.8	187.5	320.2	451.4	591.9	1056.7
GOES 10	9.5	15.7	23.3	46.3	117.2	192.5	320.3	447.0	590.8	1070.8
GOES 11	7.2	12.0	19.3	41.5	121.0	197.4	326.4	467.1	608.9	1021.5
GOES 13	8.7	15.6	21.3	46.5	121.4	197.9	371.5	449.7	577.4	1130.9
GOES 15	6.8	12.1	19.2	44.9	129.7	198.1	339.8	449.9	556.5	1074.2

3. Methods for preparing the dataset

We used an in-house software WASPE (Web App for Solar Particle Events) to help generating a homogeneous proton flux dataset for SEP environment modeling. All available 5-min averaged proton data from GOES 6-15 at National Centers for Environmental Information website (<https://satdat.ngdc.noaa.gov/sem/goes/data/avg/>) were downloaded and stored locally, which can be retrieved for any time from 1986-01-01 to 2020-02-29. The plotting library dygraphs (<https://dygraphs.com/>) was used to visualize flux variation in time and rendered a spectrum of the selected period. This tool allows zooming in the plots either horizontally or vertically, which is useful to examine the details of the records and results. Another good feature of it is to display information of each data point by just hovering over it with mouse cursor, which is very helpful to determine the onset and end of an event, and to detect gaps of bad data and data spikes. For the data gaps as reported in Raukunen et al. (2020), which are not overlapped with any significant SPE, we simply used the average flux of the two ends to fill the missing points; for spikes, we followed the algorithm described in Raukunen et al. (2020) to identify them and clean the data.

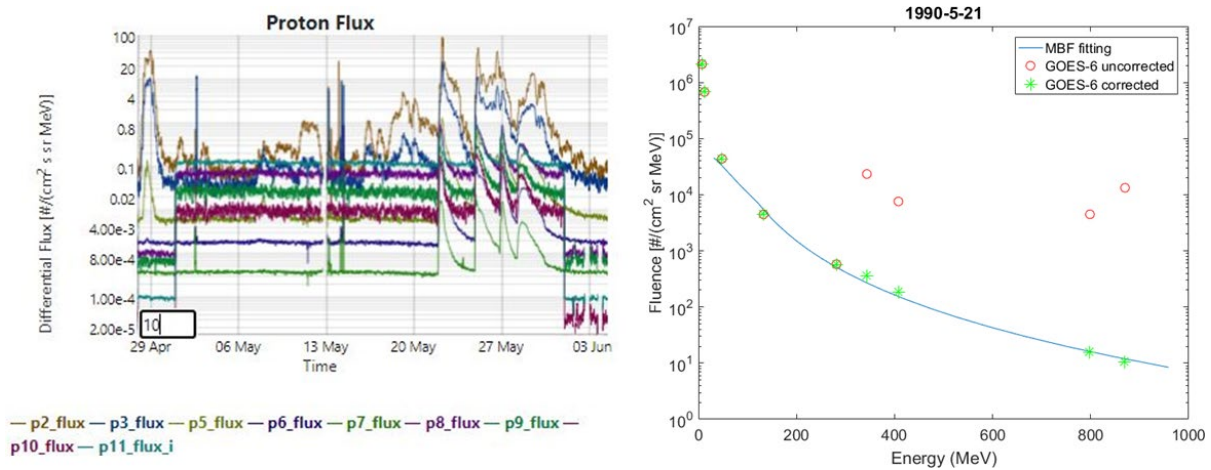


Figure 1. Elevated proton flux of HEPAD channels of GOES 6 during 1990-05-01 to 1990-05-31 (left) and event fluences of the 1990-05-21 SPE as compared with MBF spectrum (right).

As we observed in our previous work (Hu & Semones, 2022), during the two time periods observing GLEs 47-50 and 54, the background fluxes of HEPAD channels were elevated significantly higher than those before and after the periods, and the fluences of these events at the high energy channels were much larger than those of EPS channels, resulting in non-monotonic spectra in energy that are incomparable to functional fitting models (Figure 1). To remedy this caveat, we calculated the ratios of background fluxes before and after the onset of elevation. For the period of 1990-05-01 to 1990-05-31, the ratios for P8-11 are 65.8, 42.0, 284.0, and 1286.5, respectively; For the period of 1992-07-01 to 1992-12-31, the ratios are 71.0, 41.4, 312.8, and 1356.0, respectively. We found by simply dividing the elevated point fluxes during these two periods with these ratios, the corrected event-integrated fluences of the GLEs are aligned with MBF spectra derived by Koldobskiy et al. (2021). The right panel of Figure 1 shows the comparison of the 1990-05-21 event before and after the correction. All raw data were visually checked with WASPE to ensure no other such abnormal sections exists.

Except for GOES 6, other satellites in our list had some overlapped service time with at least one other satellite. Because GOES 8 provided the most reliable data for deriving SEP event fluence (Rosenqvist et al. 2005), we chose it over GOES 10 and 11 whenever its data was provided. The detectors on GOES 10 faced eastwardly during the mission (Rodriguez et al. 2014), therefore, for events with east-west anisotropic particles, the recorded flux should be different from those that faced westwardly. In addition, the data of P6 and P7 had not been reported since 2004-06-30, so we only used the data of GOES 10 in the year of 2003 to fill the gap between GOES 8 and 11, even though GOES 11 was in storage mode from 2000 to 2005, whose data quality suffers bias due to satellite spinning (Rodriguez et al. 2014). For the two EPEADs (Energetic Proton, Electron and Alpha Detectors) on both GOES 13 and 15, we always chose the one facing westward. The data quality of GOES 13 and 15 is similar (Rodriguez et al. 2014); GOES 15 is preferred over GOES 13 simply because it was the last mission of this series, and its service time is much longer than GOES 13 (Table 2).

Table 2. Selected time of GOES 6-15 to derive a uniform dataset.

Satellites	Start Date	End Date
GOES 6	1986-01-01	1994-12-31
GOES 8	1995-01-01	2002-12-31
GOES 10	2003-01-01	2003-12-31
GOES 11	2004-01-01	2010-12-31
GOES 15	2011-01-01	2019-12-31

To create a homogeneous time series of proton fluxes from the measurements of multiple missions throughout the period 1986-2019, we followed the work of Jiggins et al (2012) to rebin the data into standard energy bins. We decided to create 11 new bins exponentially distributed covering the range from 10 to 1000 MeV, as this range is encompassed in the range of the effective energies of the chosen GOES missions except for GOES 6 (Table 1), and the energies in this range are most relevant to radiation exposure analysis for space vehicles (Figure 3 in Hu et al., 2020). The rebinning of the 10 new channels of GOES 6 and 11 new channels of GOES 8-15 was done point-by-point using a piecewise power law to interpolate between the two closest

energies in the raw data. To extrapolate GOES 6 measurements to channel 11 (with energy of 1000 MeV) for each time point, the slope of P8 to P11 was first checked to see if the fluxes were monotonically decreasing, as on many occasions the proton fluxes of higher energies are higher than those of lower energies due to contaminations and Galactic Cosmic Rays (GCRs) in the HEPAD measurements (Smart & Shea, 1999; Bruno, 2017). Extrapolation was proceeded only when this condition was satisfied. We found this condition was generally met during the periods of significant events, especially when there were elevated flux measurements in all HEPAD channels.

4. Solar radiation environment model update

4.1. Event definition

Traditionally, the onset and end of an SPE are defined as the first and last time points of a period with continually elevated proton fluxes higher than a threshold (Feynman et al., 1990; Jiggins et al., 2012). However, because of the modulation of solar cycles, the background fluxes change significantly from the solar minimum to the solar maximum, and the difference can be as large as 6 times (Xapsos, 2019). If a fixed flux were chosen as the threshold to determine the onset and end of an event, the duration of a same event would be different if it occurred at different times in solar cycles, and a certain part of the elevated measurements relative to the background might be disregarded. To avoid this problem, we used the background fluxes as references for the threshold of an event, which are not fixed but varying along solar cycles. The algorithm to automatically calculate the background and to determine the onset and end of an event was reported in our previous work (Hu et al., 2020). We modified it to calculate 3 background fluxes, i.e., 1 day, 7 days, and 28 days before a time point to be checked if it can be considered as the onset of an event. The lowest one-day average flux of these three levels was considered as the pre-event background, and a value of 1.8 times the background was used as the threshold, which was a bit lower than the previous algorithm (Hu et al., 2020). If fluxes of 24 consequent time points (i.e., 2 hours) are above it, the first point was considered as the start of an event.

Following the work of Jiggins et al. (2012), we chose channel 1 fluxes (F1, at 10 MeV) to check if SPEs occurred, making sure all events were considered that could be significant in terms of their peak flux or their integrated flux (fluence) values in any of the 11 energy channels. A minimum dwell time of 24 h was introduced such that if the flux rose above the threshold again within 24 h of the end of an event, the enhancements were treated as the same event. In addition, a minimum event duration of 24 h and a minimum event fluence of $1.29\text{E}+4 \text{ cm}^{-2} \text{ sr}^{-1} \text{ MeV}^{-1}$ were used to remove erroneous and insignificant events. The automatic SPE detecting algorithm identified 230 SPEs in the dataset, which are comparable to the lists of the National Oceanographic and

Atmospheric Administration (NOAA) SEP events¹ and the Solar Energetic Particle Environment Modelling (SEP-EM) reference events².

4.2. Background removal

All pre-event background fluxes were recorded during the processing steps and compared with the Sunspot Numbers (SSN) as the solar modulation indexes, which are plotted in the left panel of Figure 2. The background fluxes of several events did not follow the trend of anti-correlation of the solar modulation. We checked each with the WASPE tool and found all the enhanced backgrounds were caused by one or more events occurred immediately before the event being analyzed. The impacts to the duration and fluence size of these events were found to be insignificant, because, for the flux of low energy protons in a typical event, the elevation relative to the pre-event background is usually several order of magnitude. Their impacts to the analysis of higher energy protons are also minimal. The right panel of Figure 2 shows the pre-event background fluxes for channel 6 (i.e., 100 MeV), which are perfectly anti-correlated with the solar modulation for all events.

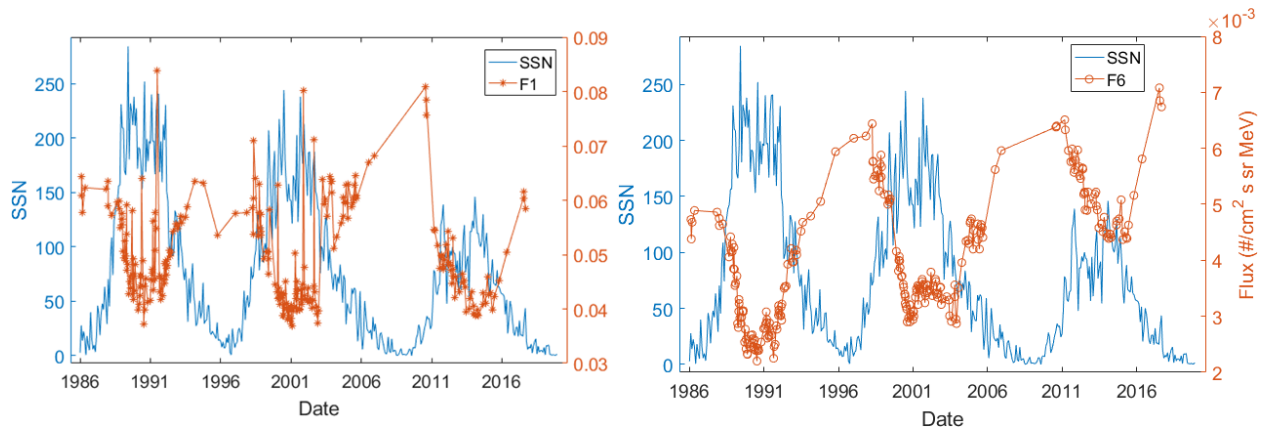


Figure 2. Pre-event background fluxes of channel 1 (F1) and channel 6 (F6) as correlated with the solar modulation index SSN (Sunspots Numbers).

To remove the background for each channel, we assumed 20% noise level for each, according to the recent work of Bruno (2017). These backgrounds are known not of solar origin but are induced by instrument noise and GCR. Because in most events the durations of the elevation period for low energy protons are generally much longer than those for high energy protons, for F6-11 of each event, we processed the data only during the elevation period of F6, so that the background noises outside the periods of real elevation in these channels have no impacts to event fluences. After the first round of process, we found, among the 230 events, there are 12 events that have zero accumulated fluence at channel 7 but some of these 12 events have non-zero fluences

¹ <http://umbra.nascom.nasa.gov/SEP/>

² http://dev.sepem.oma.be/help/event_ref.html

at channels 8-11, indicating the noise levels in these high energy proton detectors are higher than the standard 20% level. We checked the 12 events in details and tried with higher noise levels for F8-11, such that accumulated fluences of F8-11 are all zeros for these events, and the number of events with non-zero fluences are consistently decreased with the increasing energies, while the event-integrated fluences are not over-corrected after removing the backgrounds for the channels. We found the factors of 1.23, 1.80, 1.80 and 1.42 are the optimal noise levels for these 4 channels (Table 3).

To check whether these noise levels are reasonably applied, we assumed the fluence thresholds T of each channel follow a power law given by

$$T = A E^{-b} \quad (1)$$

such that the numbers of events detected in each channel can be in a reasonable order. Following the work of Jiggins et al. (2012), the constant A and index b were calculated from the defined thresholds for the lowest energy channel (F1) and the highest energy channel (F11). From all the events identified by the automatic detecting algorithm, we chose the fluence of the 2005-01-05 event as threshold for F1, which is $1.29\text{E}+4 \text{ cm}^{-2} \text{ sr}^{-1} \text{ MeV}^{-1}$, as all events with less fluences are found to be either erroneous or insignificant with the WASPE tool. For the threshold of F11, we chose the fluence of the event 1998-08-22, which is $1.48\text{E}-1 \text{ cm}^{-2} \text{ sr}^{-1} \text{ MeV}^{-1}$, as this is the smallest GLEs in term of the proton fluences with high energies during the years of 1986-2019 (Koldobskiy et al., 2021). With these definitions, the parameters b and A can be readily obtained:

$$b = \frac{\ln(1.29\text{E}+4) - \ln(1.48\text{E}-1)}{\ln(1000) - \ln(10)} = 2.47$$

$$A = \exp(\ln(1.29\text{E}+4) + b \ln(10)) = 3.81\text{E}+6$$

Using the formula (1), the thresholds for channels 2-10 are obtained and listed in Table 3.

Table 3. Rebin energies for the standard dataset and noise level, event fluence threshold, and number of events for each channel.

Channels	Rebin Energy (MeV)	Noise Level	Fluence Threshold (#/cm ² sr MeV)	Number of Events
1	10.0	1.20	1.29E+4	230
2	15.8	1.20	4.17E+3	214
3	25.1	1.20	1.33E+3	202
4	39.8	1.20	4.25E+2	186
5	65.1	1.20	1.26E+2	163
6	100.0	1.20	4.37E+1	162
7	158.5	1.20	1.40E+1	128
8	251.2	1.23	4.49E+0	116
9	398.1	1.80	1.44E+0	89
10	630.9	1.80	4.62E-1	69
11	1000.0	1.42	1.48E-1	47

After these processing steps, the list of SPEs (Appendix) during the past 3 solar cycles includes 230 events at an average of 6.76 per year. We chose 1989-11, 2001-11, and 2014-04 as the peaks of cycles 22, 23, and 24, respectively, and the span of 2.5 years before and 4.5 years after the peaks as solar maximum, such that 198 events are at solar maximum (9.43 per year), and 32 events are at solar minimum (2.46 per year). The numbers of events with fluence beyond the thresholds of each channel during the past 3 solar cycles (Table 3) as well as those during solar maximum (Table 4) are consistently decreasing as the energies increase, indicating the optimal noise levels for F8-11 are appropriately determined.

4.3. Fluence distribution

To develop a solar particle event model predicting the highest fluences over a user-specified mission duration as a function of confidence level, the ESP-PSYCHIC approach starts with fluence distribution fitting through the application of Maximum Entropy Principle (Xapsos et al., 1998; Xapsos, 2006), which leads to a truncated power function for event fluences during solar maximum period (Xapsos et al. 1999):

$$N = N_{tot} \left[\frac{\phi^{-b} - \phi_{max}^{-b}}{\phi_{min}^{-b} - \phi_{max}^{-b}} \right] \quad (2)$$

where N is the number of events per solar maximum year having a fluence greater than or equal to f , N_{tot} is the total number of events per solar maximum year having a fluence greater than or equal to f_{min} , $-b$ is the index of the power function, and f_{max} is the maximum event fluence. This function behaves like a power function with an index of $-b$ for $f \ll f_{max}$ and goes smoothly to zero at the upper limit f_{max} (Xapsos, 2006). We followed this scheme to update the worst case SPE fluence model with the new dataset we developed.

We used the `curve_fit` method of the `scipy.optimize` module (https://docs.scipy.org/doc/scipy/reference/generated/scipy.optimize.curve_fit.html) to find the best-fit parameters of Eq. (2) for the fluences obtained through the automatic SPE detecting algorithm, assuming to f_{min} are the fluence thresholds for 11 channels as reported in Table 3 and N_{tot} are the numbers of events for these channels as reported in Table 4. Because we are more interested in modelling of events with larger fluences, we set the optional parameters “sigma” of the fitting method to be 1.0 for the 75% events with lower fluences, 0.01 for the 25% events with higher fluences, and 0.001 for the highest event, for each channel. The parameter “sigma” represents the relative standard errors of the data targeted for modeling; therefore, the smaller values tune the method to find parameters such that the function of Eq. (2) fit those data points closer than others.

Table 4. Number of events during solar maximum and fitting parameters according to maximum entropy theory

Channels	Number of Events	b	ϕ_{max}
1	198	0.215	2.37E+8

2	182	0.240	1.08E+8
3	173	0.290	6.22E+7
4	157	0.305	1.95E+7
5	140	0.288	3.97E+6
6	140	0.306	1.19E+6
7	110	0.257	2.92E+5
8	100	0.283	8.04E+4
9	82	0.315	2.01E+4
10	62	0.343	3.62E+3
11	42	0.280	4.60E+2

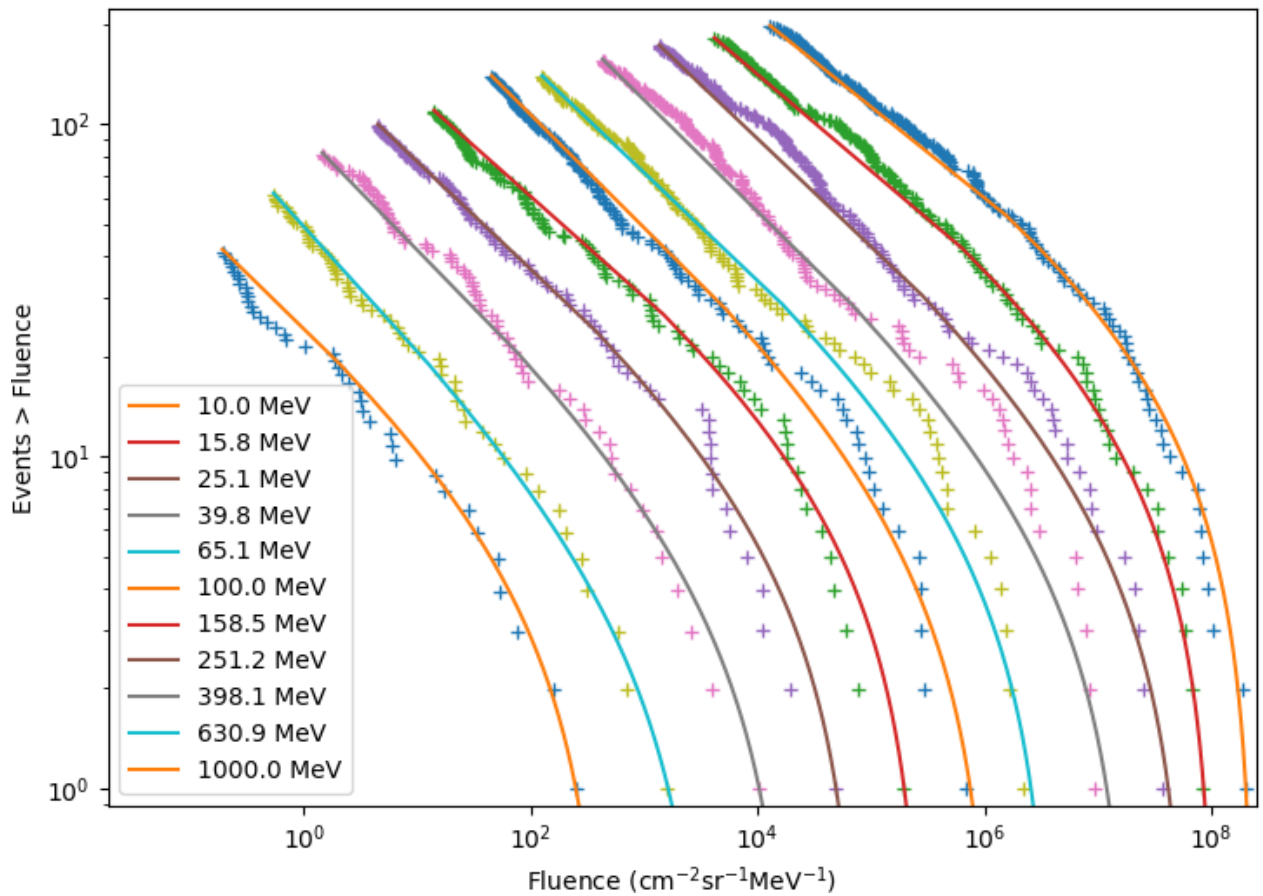


Figure 3. Comparison of the distribution function fitting with 3 solar cycles of data during solar maximum. Distribution functions derived from the parameters in Table 4 (solid lines) overlay the measured fluence values of individual SEP events for each energy (crosses).

The fitting parameters for event fluences are reported in Table 4, and comparison of the distribution of SPE fluences predicted by equation (2) with data is shown in Figure 3. Although the probability distribution functions capture the essential features of SPE magnitude distributions at all energy levels, i.e., following a power function for small event sizes and falling off rapidly for very large events, discrepancies between data and

functions are clear for some channels such as F3-5. Better fitting could be achieved if using a combination of piece-wise continuous functions to fit different sections of the distributions such as in Robinson et al. (2019), this was not pursued in this work for simplicity. Because the fitting procedure was conducted upon limited data, such uncertainties were unavoidable to associate with the parameters (Xapsos et al., 1999). In the following section of upper limit modeling, we will show the method to assess the uncertainties which make the estimation reasonable. Most of the power indexes (b in Table 3) are lower than 0.36 that was found in the work of Xapsos et al. (1999), which may be related to the differences of datasets and proton fluxes that are used for modeling. The indexes as well as $\phi_{\max}$ of F1-7 are very similar to those reported in Jiggins et al. (2012), indicating the results are consistent if the (same) differential proton fluxes are used, no matter what datasets are used.

4.4. Worst case statistical model

Once the fluence distributions are obtained, ESP-PSYCHIC approach uses the extreme value theory to determine the worst-case event as a function of confidence level and mission duration (Xapsos et al., 1998). Assuming the occurrence of SPEs is a Poisson process, the probability of the worst-case event that will occur over a period of T solar maximum years is given by

$$F_T(M) = \exp \{N_{tot}T[1 - P(M)]\} \quad (3)$$

where F_T is the desired confidence level, and $P(M)$ is the cumulative distribution of $M = \log \phi$ and is related to event fluence ϕ in the following way:

$$P(\phi) = \frac{\phi_{\max}^{-b} - \phi^{-b}}{\phi_{\min}^{-b} - \phi_{\max}^{-b}} \quad (4)$$

As all other parameters are known for each energy level as listed in Table 4, it is ready to calculate the fluences at all energy levels and get the spectrum of the worst-case event that could occur during a mission of known length with a confidence level.

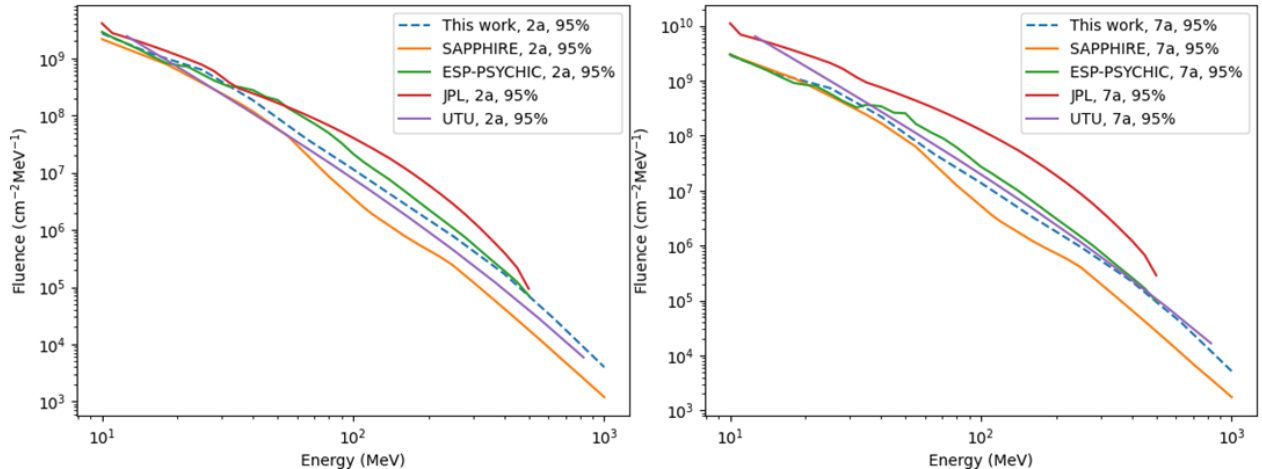


Figure 4. Comparison of worst-case event spectra of this work with SAPHIRE, ESP-PSYCHIC, JPL, and UTU model outputs for a 2-year mission and a 7-year mission during solar maximum at 95% confidence level.

Figure 4 shows the results of worst-case event spectra for a 2-year mission and a 7-year mission during solar maximum at 95% confidence level, along with the outputs of SAPHIRE, ESP-PSYCHIC, and JPL models hosting at SPENVIS website (<https://www.spenvis.oma.be/>), and of UTU model (Raukunen et al., 2018) at <https://swe.ssa.esa.int/utu-srl-federated>. The SPENVIS website extends ESP-PSYCHIC and JPL models to 500 MeV, while SAPHIRE and UTU models use different methods to simulate probability of worst-case event fluences up to 1000 MeV (Jiggins et al., 2018; Raukunen et al., 2018). For both missions, the ESP-PSYCHIC fluences are higher than the results of this work for energies > 30 MeV, but gradually converge as energies increase to the limit (500 MeV). The higher fluences in the energy range 30-500 MeV of ESP-PSYCHIC is possibly due to the 1972-08-04 event, which has the highest fluence for protons with energy > 30 MeV in space era. Fluences of JPL model are higher at all energy levels, and discrepancies increase for longer mission time (Figure 4). The results of SAPHIRE model are close to ESP-PSYCHIC and this work at low energies for 7-year mission, but are lower for 2-year mission, and for energies > 60 MeV, the fluences are lower by a factor of 3-4. This may be related to the lower effective energies of GOES P6 and P7 detectors for the calibrated dataset as compared to our work (Hu & Semones, 2022). The closest results to this work are those simulated by the UTU model, especially for the 7-year mission with energies > 30 MeV (Figure 4). This similarity is interesting as both approaches utilized the spectra of historical GLEs, though the methodologies are vast different.

4.5. Upper limits modeling

A unique feature of ESP-PSYCHIC approach is the capability to estimate the upper limits for SPE fluences (Xapsos 2006). Because the values of $\phi_{\max}$ are determined from limited data, the model applies a parametric “bootstrap” technique to assess the uncertainties of the upper limits. The idea is to randomly select event fluences according to the distribution given by equation (2), until the number of events in the distribution for each energy level is simulated. The simulated data is then used to fit the same equation, and a set of parameters can be extracted. The procedure is repeated, and each time the parameters have different values. After a number of simulations, the standard deviation of the parameter of interest can be determined.

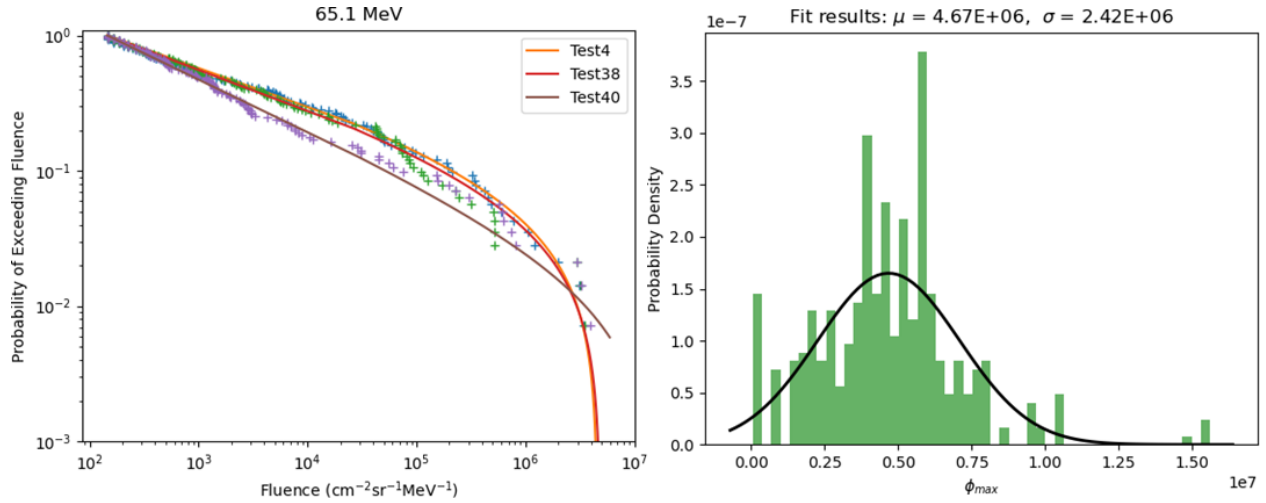


Figure 5. Resampled fluences, fitting and parameter uncertainty estimation using the parametric “bootstrap” technique. Left panel shows 3 simulation results of randomly generated event fluences for channel 5 and their fitting according to equation (2), and right panel shows the histogram of normal distribution fitting of parameter $\phi_{\max}$ for 400 simulations.

Figure 5 shows some of the resampled results. For each simulation, a number of random seeds were first generated corresponding to the number of events for the channel as in Table 4, which were used to generate random probabilities between 0 and 1. Then equation (2) was used to find the best fluences that match the probabilities. Because the probabilities were randomly generated, the calculated fluences of each simulation were unique from others, and the fitting parameters for each were unique. There were cases for the high energy channels that the highest simulated parameters were orders of magnitude larger than the average, and they were regarded as non-physical and discarded in the following uncertainty estimation. The simulated $\phi_{\max}$ were fitted with normal distribution function, with mean parameter μ and stand deviation σ reported in Table 5 for each channel.

Table 5. Resampled fitting parameters for $\phi_{\max}$ and the standard deviations for all channels.

Channels	μ	σ	$\phi_{\max} + 1\sigma$
1	1.74E+8	1.12E+8	2.86E+8
2	9.34E+7	4.44E+7	1.38E+8
3	7.47E+7	3.16E+7	1.06E+8
4	2.48E+7	1.39E+7	3.87E+7
5	4.67E+6	2.42E+6	7.09E+6
6	1.56E+6	8.18E+5	2.38E+6
7	3.28E+5	1.53E+5	4.81E+5
8	9.31E+4	4.54E+4	1.38E+5
9	2.72E+4	1.78E+4	4.50E+4
10	7.10E+3	8.79E+3	1.59E+4
11	6.42E+2	7.32E+2	1.37E+3

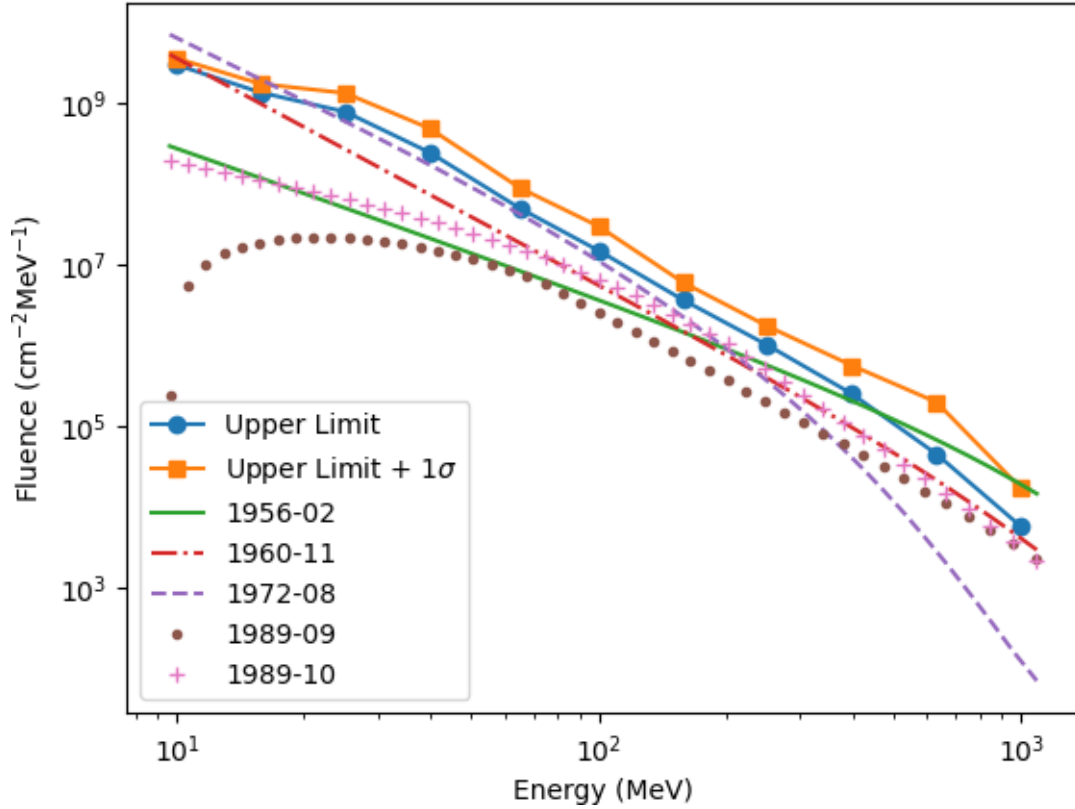


Figure 6. Spectra of upper limit and plus one standard deviation of this work with comparison of the spectra of historical large events.

The estimated upper limits for fluences at different energy levels as well as their standard deviations provide a practical and objectively determined guideline for use in limiting design costs (Xapsos, 2006). The uncertainty estimation of the upper limits is important, as the fitting of the fluences of historical events to the truncated power law function can have large deviations (Figure 3), in addition, the data available for modeling are limited and larger events are known to occur out of the period 1986-2019. In Figure 6, we compare the spectra of upper limit and plus one standard deviation of this work with the spectra of some historical large events, which were generated recently based on revised space-borne/ionospheric data and ground-based neutron monitors (Koldobskiy et al., 2021). The 5 episodes from 1956 to 1989 comprise of 1, 3, 2, 1 and 3 Ground Level Enhancements (GLEs), respectively (Raukunen et al., 2018). The upper limits are sufficiently covering the fluences of the severest events presented except for the 1956-02 event beyond 400 MeV, even though the data set used in this work is limited to the period of 1986-2019. The upper limit + 1σ can take account of the high energy tail of the spectrum of the 1956-02 event and can be considered as a combination of the 1972-08 and 1956-02 episodes, a hypothetical extreme event previously suggested for spacecraft designers (Anderson et al., 1994; Xapsos, 2006).

5. Summary and discussion

We have reported a new solar proton data set recorded by the EPS and HEPAD instruments onboard the GOES series during the last 3 solar cycles and used it to

update the worst case fluence model through the standard ESP-PSYCHIC approach. The HEPAD measurements are known to be contaminated with higher level noises than the EPS measurements. In our recent work, we used the spectra of past GLEs modeled with improved space-borne data and ground-based neutron monitor measurements and achieved a set of effective energies for the 4 HEPAD channels consistent with other multiple sources, including the bow tie analysis, PAMELA measurements, and GOES-R records of the new suite of energetic particles detectors (Hu & Semones, 2022). This makes it feasible to build up a long duration, contiguous, and homogenous solar proton data with energy extended to as high as 1000 MeV. To our knowledge, this is the first data set that have a such high energy coverage in the space radiation environment modeling community. The contribution of high energy protons is important to radiation analysis for current space technology, as most current state-of-the-art spacecraft are designed with thick shielding and only the high energy protons can penetrate the shielding and induce secondary particles to enhance radiation inside vehicles.

To build a proton data record with only solar contribution, we followed an algorithm to remove the background fluxes of all energy channels which are due to instrument noise and GCRs. The noise levels of the data in high energy channels are hard to determine, hindering its usage for a long time. We identified a procedure to estimate these by requiring the thresholds of event definition for all channels follow a universal power law, and found that, after applying the noise levels, the number of events detected at each channel decreases gradually as energy increases, no matter solar minimum periods are included or not. With this procedure, the background fluxes are found well anti-correlated with the solar modulation indexes in the past 3 solar cycles. Using the pre-event background fluxes as reference rather than fixed thresholds, an automatic algorithm detected 230 SPEs during the period of 1986-2019, a list similar to other investigations. As the background fluxes vary significantly from solar minima to solar maxima, the calculated event durations as well fluences should be more accurate than obtained with a fixed threshold for all events.

Following the standard ESP-PSYCHIC approach, we obtained an updated worst case fluence model as a function of mission duration and confidence level. The modeling results are close to the original ESP-PSYCHIC model but with extended energy coverage up to 1000 MeV. The discrepancies at energy > 30 MeV can be related to the earlier large events that are not included in our data set. The projected spectrum lies between the JPL model and the SAPPHIRE model, similar to previous comparison of these models with the ESP-PSYCHIC model (Jiggins et al., 2018). Comparing with the two models with extension to 1000 MeV, the SAPPHIRE fluences are lower by a factor of 3-4 for energies > 60 MeV, which may be related to the lower effective energies of GOES P6 and P7 detectors for the calibrated dataset as compared to our work (Hu & Semones, 2022). The UTU modeling results are very close to this work, which is interesting as both approaches utilized the spectra of historical GLEs, though the methodologies are vast different. The uncertainty estimation of the upper limits via the parametric “bootstrap” technique indicates the spectrum of the upper limit $+ 1\sigma$ can be considered as a perfect combination of the 1972-08 and 1956-02 episodes, though these two large events are not included in the modeling data set. Further works can be done similarly to update the accumulative fluence model which is essential to estimate

the exploration mission cancer risks due to SPEs, and peak flux model which provides a practical and objective guideline for designing spacecraft to endure single event effects. The data set can be also applied with more advanced methodologies to develop more models for use by spacecraft designers and mission operators.

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Appendix

Table A1. List of SPEs identified with the automatic algorithm of this work. Also presented are their onset and end times, durations, event fluences, peak fluxes, and pre-event background fluxes determined through the comparison of F1 fluxes with the pre-event background fluxes.

Event	Start Time	End Time	Duration (d)	Event Fluence (#/cm ² sr MeV)	Peak Flux (#/cm ² s sr MeV)	Background (#/cm ² s sr MeV)
1	1986-02-04 09:30	1986-02-11 11:45	7.09	2.08e+06	2.47e+01	6.09e-02
2	1986-02-14 11:20	1986-02-19 14:05	5.11	2.24e+06	3.57e+01	6.44e-02
3	1986-03-06 17:55	1986-03-08 03:30	1.40	7.01e+04	3.08e+00	5.78e-02
4	1986-05-04 12:15	1986-05-06 06:55	1.78	4.39e+04	1.54e+00	5.66e-02

5	1987-11-07 23:45	1987-11-10 18:05	2.76	4.73e+05	1.82e+01	6.20e-02
6	1987-12-30 04:35	1988-01-01 15:40	2.46	8.71e+04	1.67e+00	6.25e-02
7	1988-01-02 22:45	1988-01-07 19:30	4.86	1.09e+06	1.38e+01	5.89e-02
8	1988-03-25 22:00	1988-03-27 03:50	1.24	4.37e+04	3.37e+00	5.72e-02
9	1988-08-25 03:45	1988-08-31 23:15	6.81	3.46e+05	4.33e+00	5.96e-02
10	1988-10-04 21:50	1988-10-06 16:55	1.80	4.81e+04	1.24e+00	5.70e-02
11	1988-10-12 06:20	1988-10-13 23:25	1.71	2.20e+04	7.85e-01	5.94e-02
12	1988-11-08 15:10	1988-11-12 00:55	3.41	6.61e+04	8.04e-01	5.49e-02
13	1988-11-13 10:10	1988-11-15 05:10	1.79	2.78e+04	1.03e+00	5.50e-02
14	1988-12-14 15:00	1988-12-22 19:40	8.19	2.95e+05	3.19e+00	5.54e-02
15	1988-12-25 13:25	1988-12-27 14:05	2.03	2.17e+04	4.04e-01	5.76e-02
16	1989-01-04 22:25	1989-01-06 17:10	1.78	8.06e+04	3.33e+00	5.65e-02
17	1989-01-18 09:15	1989-01-19 10:50	1.07	1.35e+04	6.51e-01	5.06e-02
18	1989-02-03 20:00	1989-02-05 03:30	1.31	6.65e+06	1.85e+03	4.94e-02
19	1989-03-08 00:45	1989-03-21 17:25	13.69	1.75e+07	1.17e+03	5.26e-02
20	1989-03-23 20:05	1989-03-28 00:15	4.17	1.49e+05	5.41e+00	4.83e-02
21	1989-04-10 17:10	1989-04-18 16:50	7.99	3.28e+06	4.09e+01	4.88e-02
22	1989-04-22 22:05	1989-04-24 19:35	1.90	2.37e+04	5.70e-01	5.03e-02
23	1989-05-01 03:40	1989-05-09 21:10	8.73	7.97e+05	1.23e+01	4.72e-02
24	1989-05-20 14:20	1989-05-31 19:30	11.22	3.96e+05	1.07e+01	4.81e-02
25	1989-06-18 15:40	1989-06-20 15:05	1.98	2.31e+04	7.87e-01	4.27e-02
26	1989-06-29 04:50	1989-07-02 09:30	3.19	9.68e+04	1.82e+00	4.51e-02
27	1989-07-24 09:45	1989-07-26 07:00	1.89	1.06e+05	2.71e+00	4.61e-02
28	1989-08-12 15:20	1989-09-07 09:05	25.74	5.50e+07	5.59e+02	4.38e-02
29	1989-09-	1989-09-	5.75	3.54e+05	4.73e+00	4.48e-02

	12 13:00	18 06:55				
30	1989-09-29 11:50	1989-10-14 12:25	15.02	2.56e+07	2.51e+02	4.28e-02
31	1989-10-19 12:55	1989-11-09 23:05	21.42	2.04e+08	6.42e+03	4.18e-02
32	1989-11-15 07:15	1989-11-20 17:35	5.43	1.56e+05	3.67e+00	4.15e-02
33	1989-11-26 20:25	1989-12-06 01:35	9.22	3.54e+07	7.42e+02	4.82e-02
34	1990-02-13 09:50	1990-02-14 13:10	1.14	1.52e+04	6.23e-01	3.98e-02
35	1990-03-19 06:10	1990-03-22 08:50	3.11	9.12e+06	1.44e+02	4.08e-02
36	1990-03-28 16:50	1990-03-30 18:45	2.08	1.09e+05	4.15e+00	4.10e-02
37	1990-04-07 05:45	1990-04-12 16:40	5.45	4.24e+05	4.84e+00	4.40e-02
38	1990-04-16 02:55	1990-04-24 19:30	8.69	4.76e+05	2.79e+00	4.13e-02
39	1990-04-28 05:00	1990-04-30 00:20	1.81	8.56e+05	2.04e+01	4.39e-02
40	1990-05-07 13:30	1990-05-12 13:20	4.99	5.27e+04	4.57e-01	4.82e-02
41	1990-05-16 01:40	1990-06-01 02:00	16.01	3.15e+06	5.66e+01	6.40e-02
42	1990-06-12 02:10	1990-06-14 20:05	2.75	8.61e+05	2.50e+01	4.89e-02
43	1990-07-13 18:05	1990-07-15 06:00	1.50	4.57e+04	1.30e+00	3.73e-02
44	1990-07-26 01:55	1990-08-08 15:10	13.55	2.80e+06	4.32e+01	3.99e-02
45	1990-08-12 00:45	1990-08-17 13:15	5.52	1.13e+05	1.46e+00	3.89e-02
46	1990-08-25 12:10	1990-08-27 08:10	1.83	2.33e+04	1.38e+00	4.10e-02
47	1990-10-23 10:45	1990-10-24 23:50	1.55	2.18e+04	4.86e-01	4.09e-02
48	1990-12-23 10:30	1990-12-25 23:40	2.55	3.88e+04	4.04e+00	4.15e-02
49	1991-01-27 00:30	1991-02-03 14:30	7.58	2.03e+06	6.36e+01	4.36e-02
50	1991-02-08 09:30	1991-02-10 06:30	1.88	9.03e+04	1.96e+00	4.37e-02
51	1991-02-25 08:45	1991-02-28 21:10	3.52	7.77e+04	2.48e+00	4.14e-02
52	1991-03-04 07:30	1991-03-06 23:55	2.68	1.93e+04	3.15e-01	4.58e-02
53	1991-03-12 08:40	1991-03-19 22:45	7.59	1.69e+05	1.64e+00	4.39e-02

54	1991-03-23 06:20	1991-04-11 19:55	19.57	7.93e+07	5.69e+03	4.34e-02
55	1991-04-22 11:40	1991-04-25 14:00	3.10	6.32e+04	9.14e-01	5.07e-02
56	1991-05-04 06:00	1991-05-06 21:05	2.63	2.78e+04	4.07e-01	5.78e-02
57	1991-05-08 01:30	1991-05-14 16:15	6.61	1.73e+06	5.02e+01	4.55e-02
58	1991-05-19 00:15	1991-06-22 17:15	34.71	2.80e+07	2.47e+02	5.48e-02
59	1991-06-29 23:20	1991-07-13 07:50	13.35	2.73e+07	8.48e+02	8.39e-02
60	1991-08-25 19:35	1991-09-01 16:25	6.87	2.54e+06	5.42e+01	4.31e-02
61	1991-09-06 13:05	1991-09-08 07:25	1.76	4.75e+04	1.10e+00	4.60e-02
62	1991-09-30 07:35	1991-10-05 15:35	5.33	2.56e+05	3.27e+00	4.17e-02
63	1991-10-27 23:55	1991-11-02 08:10	5.34	8.62e+05	3.41e+01	4.55e-02
64	1991-12-21 22:05	1991-12-24 11:30	2.56	3.10e+04	5.88e-01	4.55e-02
65	1991-12-25 21:30	1991-12-27 16:30	1.79	2.29e+04	9.07e-01	4.84e-02
66	1991-12-29 04:30	1991-12-31 16:30	2.50	4.08e+04	8.45e-01	4.54e-02
67	1992-01-04 09:20	1992-01-06 13:40	2.18	1.67e+04	3.79e-01	4.45e-02
68	1992-02-06 23:05	1992-02-10 16:30	3.73	1.32e+06	2.52e+01	4.87e-02
69	1992-02-17 11:00	1992-02-19 14:50	2.16	2.39e+04	1.41e+00	4.63e-02
70	1992-02-26 00:25	1992-02-29 22:20	3.91	7.97e+04	2.68e+00	4.75e-02
71	1992-03-07 18:00	1992-03-11 02:15	3.34	3.48e+04	6.35e-01	4.80e-02
72	1992-03-15 08:20	1992-03-18 08:45	3.02	1.04e+05	1.94e+00	4.69e-02
73	1992-05-09 05:05	1992-05-14 08:35	5.15	1.34e+07	1.14e+03	5.08e-02
74	1992-05-24 08:40	1992-05-25 12:10	1.15	1.83e+04	7.72e-01	4.58e-02
75	1992-06-25 20:25	1992-07-02 12:15	6.66	2.45e+06	3.60e+01	4.76e-02
76	1992-08-04 18:20	1992-08-09 03:05	4.36	1.77e+05	3.56e+00	5.42e-02
77	1992-10-30 18:45	1992-11-09 21:35	10.12	3.20e+07	3.32e+02	5.56e-02
78	1992-11-	1992-11-	1.52	4.55e+04	2.36e+00	5.53e-02

	29 10:55	30 23:20				
79	1992-12-23 03:20	1992-12-24 10:10	1.28	6.48e+04	2.16e+00	5.47e-02
80	1993-03-04 13:05	1993-03-10 09:35	5.85	2.16e+05	2.17e+00	5.70e-02
81	1993-03-12 18:40	1993-03-15 20:00	3.06	2.80e+05	6.64e+00	5.52e-02
82	1993-06-25 02:00	1993-06-29 06:55	4.20	3.98e+04	4.11e-01	5.68e-02
83	1993-08-09 03:45	1993-08-12 22:10	3.77	2.55e+04	3.51e-01	5.94e-02
84	1994-02-20 02:05	1994-02-23 14:55	3.53	2.30e+07	2.71e+03	6.15e-02
85	1994-10-19 22:15	1994-10-22 03:35	2.22	2.63e+05	7.06e+00	6.32e-02
86	1995-10-20 07:35	1995-10-22 23:45	2.67	4.02e+05	1.29e+01	5.36e-02
87	1997-11-04 07:00	1997-11-12 00:30	7.73	3.92e+06	5.31e+01	5.77e-02
88	1998-04-06 00:50	1998-04-09 01:05	3.01	2.06e+04	2.79e-01	5.75e-02
89	1998-04-20 12:15	1998-04-28 03:30	7.64	8.94e+06	1.01e+02	5.38e-02
90	1998-04-29 22:55	1998-05-07 10:30	7.48	8.57e+05	1.68e+01	5.98e-02
91	1998-05-09 06:45	1998-05-11 15:20	2.36	9.47e+04	2.13e+00	5.84e-02
92	1998-06-17 03:15	1998-06-19 03:45	2.02	3.36e+04	5.57e-01	6.40e-02
93	1998-08-22 08:50	1998-09-03 04:50	11.83	8.97e+06	1.77e+02	5.22e-02
94	1998-09-24 01:40	1998-09-27 14:30	3.53	2.80e+05	2.79e+01	5.77e-02
95	1998-09-30 14:20	1998-10-05 04:15	4.58	7.04e+06	1.54e+02	5.68e-02
96	1998-10-19 01:00	1998-10-20 15:45	1.61	2.91e+04	7.00e-01	5.49e-02
97	1998-11-06 03:45	1998-11-09 05:45	3.08	3.22e+05	5.48e+00	5.60e-02
98	1998-11-14 06:35	1998-11-18 12:25	4.24	1.10e+06	3.25e+01	5.41e-02
99	1998-11-22 08:15	1998-11-29 04:30	6.84	5.52e+04	4.46e-01	5.35e-02
100	1999-01-21 00:15	1999-01-27 10:40	6.43	3.47e+05	4.87e+00	4.92e-02
101	1999-04-24 16:10	1999-04-27 03:55	2.49	3.09e+05	7.06e+00	5.04e-02
102	1999-05-04 06:45	1999-05-10 08:10	6.06	4.67e+05	5.96e+00	5.06e-02

103	1999-05-27 12:05	1999-05-29 13:35	2.06	3.95e+04	1.31e+00	4.64e-02
104	1999-06-01 21:50	1999-06-08 23:25	7.07	1.28e+06	1.30e+01	4.92e-02
105	1999-06-25 22:40	1999-06-27 00:45	1.09	2.31e+04	9.21e-01	5.09e-02
106	1999-11-18 02:15	1999-11-20 08:35	2.26	3.07e+04	6.45e-01	4.46e-02
107	2000-01-09 17:30	2000-01-11 23:35	2.25	2.97e+04	6.65e-01	4.32e-02
108	2000-01-28 03:30	2000-01-30 11:45	2.34	2.62e+04	3.85e-01	4.29e-02
109	2000-02-11 18:30	2000-02-13 09:55	1.64	1.75e+04	1.11e+00	4.38e-02
110	2000-02-18 00:55	2000-02-21 13:50	3.54	6.05e+04	2.19e+00	4.21e-02
111	2000-03-22 17:50	2000-03-24 11:40	1.74	2.37e+04	5.63e-01	4.09e-02
112	2000-04-04 17:35	2000-04-08 03:55	3.43	1.18e+06	2.28e+01	4.21e-02
113	2000-05-15 22:30	2000-05-22 07:25	6.37	6.27e+04	8.32e-01	4.10e-02
114	2000-06-07 00:25	2000-06-14 04:40	7.18	2.46e+06	4.57e+01	3.87e-02
115	2000-06-17 08:45	2000-06-18 21:00	1.51	2.81e+04	1.15e+00	4.28e-02
116	2000-06-25 12:40	2000-06-27 12:35	2.00	6.20e+04	1.98e+00	3.87e-02
117	2000-07-11 21:15	2000-07-24 18:15	12.88	9.40e+07	1.80e+03	4.02e-02
118	2000-07-26 18:00	2000-07-31 03:10	4.38	1.20e+05	3.41e+00	3.84e-02
119	2000-08-11 14:00	2000-08-14 18:55	3.20	1.29e+05	8.44e+00	4.51e-02
120	2000-09-12 14:25	2000-09-20 07:00	7.69	6.02e+06	8.90e+01	4.10e-02
121	2000-10-16 08:40	2000-10-20 09:30	4.03	1.86e+05	2.32e+00	3.96e-02
122	2000-10-25 14:10	2000-10-29 01:20	3.47	2.59e+05	3.91e+00	3.88e-02
123	2000-10-30 14:40	2000-11-04 18:00	5.14	1.33e+05	1.83e+00	3.84e-02
124	2000-11-08 23:40	2000-12-06 23:55	28.01	7.57e+07	1.02e+03	3.97e-02
125	2001-01-05 23:55	2001-01-07 09:40	1.41	1.29e+04	4.16e-01	4.07e-02
126	2001-01-21 22:45	2001-02-01 05:30	10.28	7.98e+05	1.29e+01	3.68e-02
127	2001-02-	2001-02-	1.13	1.91e+04	8.13e-01	3.97e-02

	26 10:20	27 13:25				
128	2001-03-26 06:40	2001-03-28 13:15	2.27	1.00e+05	4.84e+00	4.02e-02
129	2001-03-29 13:25	2001-04-23 17:50	25.18	1.83e+07	9.71e+01	4.03e-02
130	2001-04-27 02:00	2001-04-29 10:45	2.36	2.36e+05	3.41e+01	4.01e-02
131	2001-05-07 14:40	2001-05-11 14:40	4.00	4.96e+05	7.73e+00	4.19e-02
132	2001-05-20 07:45	2001-05-22 23:40	2.66	3.82e+04	7.10e-01	4.28e-02
133	2001-06-02 00:35	2001-06-07 00:05	4.98	4.32e+04	5.09e-01	3.97e-02
134	2001-06-15 10:45	2001-06-19 04:20	3.73	3.80e+05	6.48e+00	4.36e-02
135	2001-08-09 19:10	2001-08-12 13:15	2.75	2.17e+05	5.70e+00	3.98e-02
136	2001-08-14 23:50	2001-08-30 05:55	15.25	1.78e+06	2.62e+01	4.00e-02
137	2001-09-15 13:05	2001-09-16 20:50	1.32	5.21e+04	2.04e+00	4.19e-02
138	2001-09-24 11:40	2001-10-13 16:50	19.22	7.76e+07	1.94e+03	4.08e-02
139	2001-10-19 03:50	2001-10-28 17:35	9.57	4.03e+05	5.36e+00	4.46e-02
140	2001-11-04 16:50	2001-11-15 17:10	11.01	1.02e+08	3.06e+03	4.16e-02
141	2001-11-17 10:05	2001-12-03 00:10	15.59	8.21e+07	3.30e+03	4.40e-02
142	2001-12-11 19:10	2001-12-14 05:10	2.42	4.06e+04	9.82e-01	4.76e-02
143	2001-12-16 04:55	2001-12-17 20:35	1.65	1.57e+04	4.46e-01	4.38e-02
144	2001-12-26 05:50	2002-01-28 15:30	33.40	1.10e+07	6.79e+01	4.24e-02
145	2002-02-20 07:05	2002-02-22 06:15	1.97	3.27e+04	2.19e+00	4.15e-02
146	2002-03-16 03:05	2002-03-25 12:25	9.39	2.14e+06	1.45e+01	4.39e-02
147	2002-04-17 11:10	2002-05-03 01:15	15.59	2.01e+07	3.19e+02	4.13e-02
148	2002-05-22 07:20	2002-05-26 20:20	4.54	2.60e+06	3.41e+02	4.04e-02
149	2002-07-07 13:30	2002-07-12 06:05	4.69	1.52e+05	3.04e+00	4.02e-02
150	2002-07-16 13:05	2002-07-31 21:20	15.34	4.69e+06	9.43e+01	4.16e-02
151	2002-08-14 03:40	2002-08-27 07:55	13.18	4.51e+06	4.42e+01	4.22e-02

152	2002-09-06 05:05	2002-09-11 08:25	5.14	8.18e+05	6.74e+01	4.32e-02
153	2002-10-31 03:40	2002-11-05 06:35	5.12	5.76e+04	5.85e-01	3.92e-02
154	2002-11-09 16:50	2002-11-13 06:15	3.56	2.41e+06	8.75e+01	4.03e-02
155	2002-11-25 14:05	2002-11-28 20:50	3.28	8.97e+04	2.01e+00	3.74e-02
156	2002-12-19 23:35	2002-12-21 02:35	1.12	2.70e+04	1.09e+00	3.97e-02
157	2003-04-07 16:00	2003-04-10 06:00	2.58	8.63e+04	2.29e+00	5.81e-02
158	2003-05-28 06:25	2003-06-01 19:20	4.54	3.95e+06	1.40e+02	5.93e-02
159	2003-06-16 18:15	2003-06-22 19:25	6.05	9.94e+05	2.15e+01	6.01e-02
160	2003-10-22 14:40	2003-10-25 15:10	3.02	4.79e+05	2.14e+01	6.16e-02
161	2003-10-26 18:00	2003-11-16 02:55	20.37	1.89e+08	1.01e+04	6.29e-02
162	2003-11-18 13:30	2003-11-25 17:20	7.16	1.15e+06	1.24e+01	6.07e-02
163	2003-12-02 13:20	2003-12-06 23:50	4.44	5.08e+05	7.79e+00	5.97e-02
164	2004-01-21 06:30	2004-01-22 10:40	1.17	1.35e+04	9.24e-01	5.12e-02
165	2004-04-11 06:35	2004-04-13 17:20	2.45	8.93e+05	2.06e+01	5.32e-02
166	2004-07-22 18:15	2004-08-02 21:55	11.15	4.88e+06	8.94e+02	5.59e-02
167	2004-09-13 19:00	2004-09-18 14:05	4.80	6.84e+06	1.36e+02	5.70e-02
168	2004-09-19 18:10	2004-09-22 13:30	2.81	3.07e+05	1.11e+01	6.05e-02
169	2004-10-30 09:50	2004-11-03 13:20	4.15	1.98e+05	6.48e+00	5.88e-02
170	2004-11-06 23:45	2004-11-17 22:35	10.95	1.24e+07	1.67e+02	5.96e-02
171	2004-12-03 13:45	2004-12-06 18:15	3.19	7.63e+04	1.31e+00	6.08e-02
172	2005-01-15 08:20	2005-01-25 12:15	10.16	3.75e+07	3.95e+02	5.67e-02
173	2005-01-28 12:40	2005-01-30 16:15	2.15	1.69e+04	3.30e-01	6.29e-02
174	2005-05-06 06:00	2005-05-09 04:20	2.93	1.74e+05	2.17e+00	5.82e-02
175	2005-05-13 20:00	2005-05-18 18:30	4.94	1.52e+07	2.06e+03	5.68e-02
176	2005-06-	2005-06-	2.11	2.08e+05	4.13e+00	6.05e-02

	16 20:45	18 23:30				
177	2005-07-10 03:05	2005-07-12 02:10	1.96	3.31e+04	1.01e+00	6.27e-02
178	2005-07-13 18:05	2005-07-20 15:35	6.90	2.79e+06	2.29e+01	6.02e-02
179	2005-07-26 23:45	2005-08-06 11:05	10.47	3.21e+06	1.45e+01	6.25e-02
180	2005-08-22 03:30	2005-08-27 19:55	5.68	7.86e+06	1.02e+02	6.09e-02
181	2005-09-07 10:25	2005-09-20 14:05	13.15	4.22e+07	5.91e+02	6.03e-02
182	2006-07-06 13:35	2006-07-08 02:35	1.54	2.66e+04	6.58e-01	6.70e-02
183	2006-12-05 17:20	2006-12-17 15:50	11.94	3.69e+07	4.35e+02	6.81e-02
184	2010-08-02 11:20	2010-08-04 10:15	1.95	8.01e+04	2.97e+00	7.47e-02
185	2010-08-14 11:20	2010-08-16 01:30	1.59	5.56e+04	2.30e+00	7.56e-02
186	2010-08-18 09:10	2010-08-19 16:55	1.32	3.53e+04	1.18e+00	7.35e-02
187	2011-03-07 23:00	2011-03-12 07:55	4.37	4.32e+05	4.28e+00	5.46e-02
188	2011-03-21 05:35	2011-03-23 08:35	2.12	6.97e+04	1.95e+00	5.45e-02
189	2011-06-05 18:55	2011-06-19 06:40	13.49	5.93e+05	6.74e+00	4.97e-02
190	2011-08-02 08:30	2011-08-10 08:50	8.01	1.23e+06	1.94e+01	4.75e-02
191	2011-09-06 03:30	2011-09-09 17:10	3.57	5.16e+04	7.95e-01	4.84e-02
192	2011-09-23 05:05	2011-09-29 14:20	6.39	4.56e+05	7.88e+00	4.99e-02
193	2011-10-23 05:10	2011-10-25 17:25	2.51	8.71e+04	2.36e+00	4.73e-02
194	2011-11-26 09:55	2011-11-29 21:35	3.49	2.92e+05	9.61e+00	4.90e-02
195	2012-01-20 18:00	2012-02-01 20:05	12.09	1.69e+07	6.88e+02	5.18e-02
196	2012-02-25 07:05	2012-02-27 21:10	2.59	4.22e+04	7.12e-01	4.81e-02
197	2012-03-05 04:25	2012-03-16 13:50	11.39	2.16e+07	8.07e+02	5.32e-02
198	2012-05-17 01:45	2012-05-20 22:20	3.86	8.05e+05	2.47e+01	4.80e-02
199	2012-05-27 00:00	2012-05-29 16:40	2.69	1.05e+05	3.45e+00	4.71e-02
200	2012-06-15 15:35	2012-06-17 15:10	1.98	7.09e+04	3.43e+00	4.47e-02

201	2012-07-07 01:10	2012-07-11 13:45	4.52	2.50e+05	2.56e+00	4.49e-02
202	2012-07-12 17:25	2012-07-16 05:05	3.49	8.61e+05	1.84e+01	5.30e-02
203	2012-07-17 15:35	2012-08-03 02:30	16.45	1.61e+06	1.61e+01	4.73e-02
204	2012-09-01 04:35	2012-09-06 06:55	5.10	1.05e+06	1.20e+01	4.21e-02
205	2012-12-14 20:35	2012-12-16 13:30	1.70	2.94e+04	1.42e+00	4.04e-02
206	2013-03-16 00:55	2013-03-18 03:45	2.12	9.49e+04	4.53e+00	4.44e-02
207	2013-04-11 08:45	2013-04-15 15:55	4.30	5.29e+05	1.05e+01	4.49e-02
208	2013-04-21 10:30	2013-04-23 06:45	1.84	1.89e+04	4.07e-01	4.50e-02
209	2013-05-14 04:15	2013-05-27 06:35	13.10	1.17e+07	1.92e+02	4.16e-02
210	2013-06-21 18:05	2013-06-27 20:50	6.11	2.42e+05	2.67e+00	3.95e-02
211	2013-09-30 02:20	2013-10-03 02:50	3.02	5.07e+05	3.06e+01	3.89e-02
212	2013-10-29 10:00	2013-10-31 09:40	1.99	2.95e+04	5.36e-01	3.85e-02
213	2013-12-28 21:50	2013-12-29 23:45	1.08	1.57e+04	7.92e-01	4.06e-02
214	2014-01-06 08:15	2014-01-13 18:15	7.42	3.56e+06	6.00e+01	3.91e-02
215	2014-02-19 04:25	2014-02-20 22:25	1.75	3.64e+04	1.53e+00	3.87e-02
216	2014-02-25 07:20	2014-03-04 23:30	7.67	7.21e+05	1.01e+01	3.90e-02
217	2014-04-05 07:20	2014-04-09 04:55	3.90	3.49e+04	3.25e-01	3.99e-02
218	2014-04-18 13:45	2014-04-21 16:30	3.11	8.38e+05	9.48e+00	3.87e-02
219	2014-09-02 09:45	2014-09-14 17:30	12.32	9.51e+05	2.99e+01	4.12e-02
220	2014-11-01 20:55	2014-11-04 20:25	2.98	3.63e+04	6.66e-01	4.11e-02
221	2014-12-21 05:30	2014-12-23 12:45	2.30	3.19e+04	4.14e+00	4.32e-02
222	2015-01-29 12:20	2015-01-31 21:25	2.38	1.46e+04	3.14e-01	4.26e-02
223	2015-03-15 04:45	2015-03-17 15:10	2.43	7.89e+04	2.65e+00	4.30e-02
224	2015-04-23 05:00	2015-04-26 23:25	3.77	2.02e+04	2.28e-01	3.99e-02
225	2015-05-	2015-05-	1.00	2.95e+04	8.70e-01	3.98e-02

	12 04:55	13 04:55				
226	2015-06-18 04:50	2015-07-02 23:30	14.78	5.04e+06	2.13e+02	4.22e-02
227	2015-10-29 04:00	2015-10-30 22:50	1.78	3.84e+04	1.21e+00	4.53e-02
228	2017-07-14 04:10	2017-07-16 17:00	2.53	2.18e+05	2.74e+00	6.04e-02
229	2017-07-25 10:40	2017-07-28 17:55	3.30	2.48e+04	2.94e-01	6.16e-02
230	2017-09-04 22:40	2017-09-16 12:20	11.57	1.75e+07	1.52e+02	5.84e-02