

Comparative Analysis of Solar Proton Events at Lagrange Point-1 and the Geostationary Orbit

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INTRODUCTION

Solar proton events (SPEs), a solar energetic particle (SEP) event subclass, are typically defined as increases of fluxes of ≥ 10 MeV protons, elevating space radiation levels and posing risks to astronauts and equipment.

We investigate concurrent 10 – 50 MeV SPE differences between L1 and geostationary orbit (GEO), exploring magnetospheric transport impacts on proton variations.

We previously cataloged SPEs at GEO using GOES flux data and extend this to L1, with data from SOHO-EPHIN (processed by Dröge, H., & Heber, B. (2024)¹) as a cis-lunar proxy beyond Earth's magnetosphere.

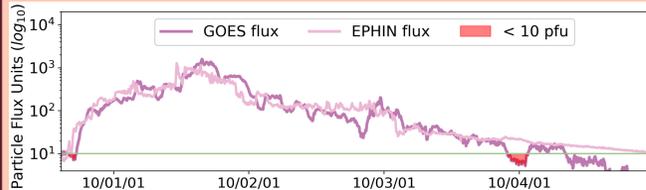


Figure 1: Example of a concurrent event and merged GOES-SPE from Table 1.

MOTIVATION

SPE variations between GEO and L1 may reveal conditions modulating fluxes reaching lunar or terrestrial surfaces.

Understanding SPE precipitation into Earth's magnetosphere is essential for accurate forecasting, particularly when localized data may be insufficient for predictions elsewhere.

With missions like Artemis, we must prioritize safe lunar operations and further understand SEP dynamics.

PROCESSING DATA

Events ≤ 10 minutes apart as well as consecutive SPEs are merged into a single event if identified as such by the other instrument (see Table 1 & Fig. 1).

		Start of SPE	Peak-flux time	End of SPE
EPHIN SPE	1.	10/1/01 12:40	10/2/01 4:10	10/4/01 23:55
Overlapping GOES SPEs	i.	10/1/01 11:55	10/1/01 12:10	10/1/01 12:45
	ii.	10/1/01 14:00	10/2/01 7:45	10/4/01 3:10
	iii.	10/4/01 6:05	10/4/01 6:40	10/4/01 11:25
GOES SPE	1.	10/1/01 11:55	10/2/01 7:45	10/4/01 11:25

Table 1: Merging 3 GOES-detected SPEs into 1 as they all occur during a single event detected by EPHIN.

Our analysis produced an SPE catalog of concurrent events detected at L1 and GEO. Across solar cycles (SCs) 23 there were 65 events, and in SC 24, only 17.

COMPARING SPEs

- ❖ We analyzed SPE differences across SCs 23 & 24, including start times, duration, etc. (see Fig. 2).
- ❖ GOES sometimes detects SPEs earlier than EPHIN, a counter-intuitive result linked to high-energy particle fluxes in GOES "contaminating" low-energy channels.
- ❖ We separate 17 potential contamination candidates (CCs, see Fig. 3) and 66 non-contaminated events for analysis. "Strong" (peak ≥ 100 pfu) and "weaker" events (peak < 100 pfu) are also analyzed separately.
- ❖ Resulting faulty early detections skew SPE parameters, affecting peak fluxes, fluence, and more.

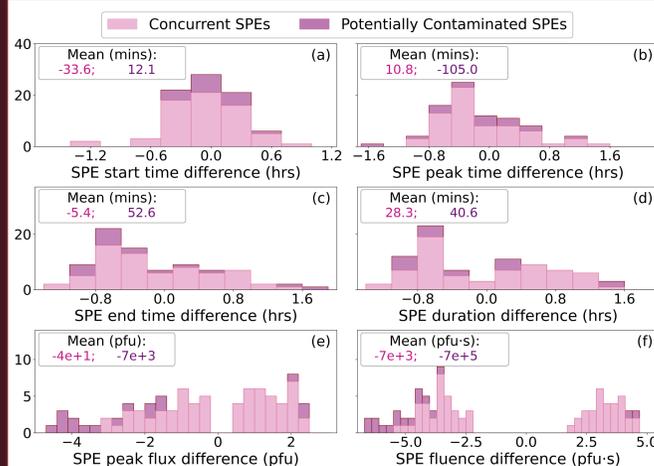


Fig 2: Signed logarithmic differences in event properties detected by EPHIN and GOES.

EPHIN also faces challenges during high-energy storms, where detector mode changes cause abrupt flux variations. These shifts currently lack a full correction algorithm. While both spacecraft exhibit data peculiarities, GOES flux contamination is more pertinent and should be accounted for.

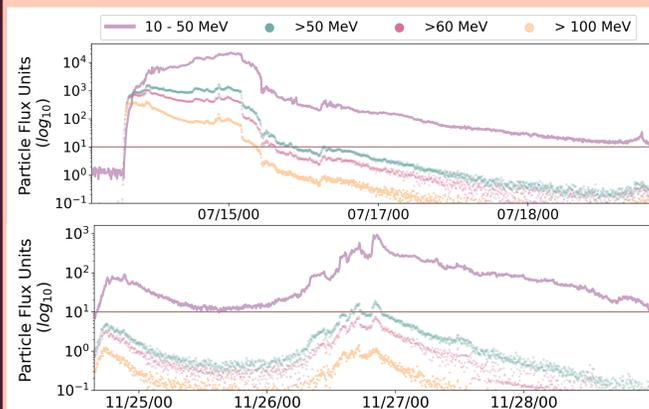


Fig 3: Examples of (top) contaminated and (bottom) non-contaminated GOES SPE flux data.

CORRELATION COEFFICIENTS

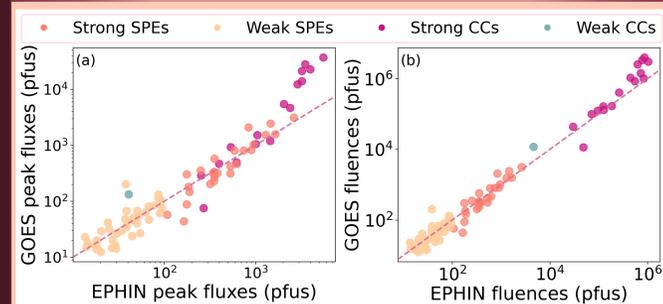


Fig 4: GOES (left) peak flux and (right) fluence detections compared to EPHIN.

Fig. 4 shows that for peak fluxes, $\sim 55\%$ of events fall below the 1-to-1 line with a median GOES:EPHIN ratio of 0.95 ± 0.30 (MAD), indicating that EPHIN generally reports higher values than GOES.

For fluences, 59% lie below the line, with a median ratio of 0.80 ± 0.28 (MAD), indicating that measurement discrepancies are slightly more pronounced for fluences.

Evaluating potential influence of external factors on flux measurements, we calculate the Pearson Correlation, Kendall τ and Spearman rank correlation coefficients for:

- SPE fluence detected by EPHIN relative to GOES.
- Local magnetic pressure at GEO relative to particle ratios between GOES and EPHIN.
- GOES data contamination relative to its position in the geocentric solar ecliptic system.
- EPHIN:GOES peak flux ratios relative to indexes: K_p , A_e , A_p , Dst , and bulk solar wind flow pressure.

PCC often yields statistically significant correlations for non-contaminated events; however, these results may be strongly influenced by outliers.

(a)	PCC with p-val		Kendall τ with p-val		Spearman ρ with p-val	
K_p	0.37	0.002	0.03	0.72	0.04	0.77
AE	0.43	3.5E-04	-0.01	0.94	-0.01	0.92
A_p	0.53	4.0E-06	0.03	0.75	0.04	0.75
Dst	-0.36	0.003	0.02	0.79	0.03	0.82
Flow Pressure	0.11	0.37	0.09	0.26	0.14	0.26

(b)	PCC with p-val		Kendall τ with p-val		Spearman ρ with p-val	
K_p	0.40	0.12	0.35	0.052	0.59	0.042
AE	0.27	0.29	0.19	0.31	0.55	0.31
A_p	0.51	0.04	0.40	0.027	0.59	0.041
Dst	-0.61	0.010	-0.49	0.006	0.05	0.017
Flow Pressure	-0.61	0.01	-0.16	0.39	-0.14	0.37

Table 2: Summary of correlation analyses. Panel (a) covers non-contaminated events; panel (b) covers CCs.

DISCUSSION

Non-parametric Spearman and Kendall τ (Table 2) methods generally yield weaker correlations, indicating that PCC alone may be misleading if not carefully interpreted.

Our analysis of SPE properties during SCs 23 & 24 comparing proton flux data from L1 and GEO highlight:

- ❖ SPEs detected only by either instrument typically exceeded the 10 pfu threshold in the 10 – 50 MeV energy range by small margins.
- ❖ EPHIN generally detected earlier SPE onsets (\sim tens of minutes), peak fluxes, and end times across both SCs.
- ❖ Peak flux and fluences from both instruments show a strong linear relationship (see Fig. 4).
- ❖ $\sim 55\%$ of SPEs show a GOES-to-EPHIN peak flux ratio < 1 , potentially indicating magnetospheric shielding effects on GOES detections.
- ❖ No clear trend was found between GOES locations and flux contamination patterns.
- ❖ Analyses showed no significant relationship between the variables listed in *Correlation Coefficients*.
- ❖ Excluding GOES CCs, events exhibit similar properties and trends across different parameters (see Table 3).

		EPHIN	GOES
Strong SPEs	# of events	26	
	Peak flux (\sim pfu)	369 ± 193	344 ± 215
	Fluence (\sim pfu)	$5.7e4 \pm 2.7e4$	$4.5e4 \pm 3.2e4$
	Duration (hrs)	44 ± 15	42 ± 18
Weak SPEs	# of events	40	
	Peak flux (\sim pfu)	38 ± 16	35 ± 18
	Fluence (\sim pfu)	$5.2e3 \pm 4.3e3$	$5.5e3 \pm 4.7e3$
	Duration (hrs)	20 ± 13	21 ± 13
Strong CCs	# of events	16	
	Peak flux (\sim pfu)	$1.8e3 \pm 1.3e3$	$3.1e3 \pm 2.7e3$
	Fluence (\sim pfu)	$3.5e5 \pm 2.8e5$	$6.3e5 \pm 5.1e5$
	Duration (hrs)	94 ± 31	91 ± 32
Weak CCs	# of events	1	
	Peak flux (\sim pfu)	41	133
	Fluence (\sim pfu)	$4.6e3$	$1.2e4$
	Duration (hrs)	23	30

Table 3: Median Properties of SPEs detected by GOES and EPHIN across SCs 23 & 24.

REFERENCES & ACKNOWLEDGEMENTS

¹Dröge, H., & Heber, B. (2024). Proton fluxes from the REleASE system from 1995 to 2016 (Version V01)
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