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GOES Solar Energetic Particle Instrument Cross Calibrations

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Cross calibration of Solar Energetic Particle (SEP) measurements in geostationary orbit

- **General approach**
  1. Identify periods when we expect detectors at different locations and with different look-directions to measure the same flux.
  2. Quantify systematic differences between flux measurements.
  3. May adjust geometric factors and/or energy bounds to bring reported fluxes into better agreement.
- **Criteria for comparisons**
  - Assuming an isotropic and homogeneous SEP distribution in near-Earth interplanetary space; we expect the same solar proton flux measurement, at different longitudes and look-directions, when the measured energies are above the proton cutoff energies for all directions of arrival within the detector fields-of-view and at both spacecraft locations [Kress et al., 2013; 2021; Rodriguez et al., 2014].
  - At energies below the proton cutoff energy, there are natural, geophysical differences between proton fluxes at different LTs and/or in different look directions.
- **Additional Considerations**
  - At SEP event onset, interplanetary SEP flux is often anisotropic. During the peak and declining phase, the flux usually becomes more isotropic [Reid, 1964; Desai & Giacalone, 2016].
  - During geomagnetically disturbed periods, magnetospheric shielding of interplanetary ions is suppressed allowing solar protons with energies above a few MeV unimpeded access well inside of geosynchronous. This enables cross calibration of SGPS ~2-80 MeV energy channels.

GOES 16-19 Space Environment In-Situ Suite (SEISS)
Solar and Galactic Proton Sensor (SGPS)

Solar and Galactic Proton Sensor

- 2 units on each GOES-R series spacecraft, one looking east and one west
- 3 solid state telescopes on each unit
- 1-500 MeV protons in 13 differential channels, plus >500 MeV integral channel
- 4 MeV-500 MeV alphas in 11 energy bands
  (Included in operational data after 2022-04-25.)

GOES-R Series SGPS Proton Energy Channels by Telescope			(MeV)
SGPS Tel. 1	SGPS Tel. 2	SGPS Tel. 3	EPS/EPEAD
P1: 1.0–1.9	P6: 25–40	P8A: 83–99	P1: 0.74–4.2
P2A: 1.9–2.3	P7: 40–80	P8B: 99–118	P2: 4.2–8.7
P2B: 2.3–3.4		P8C: 118–150	P3: 8.7–14.5
P3: 3.4–6.5		P9: 150–275	P4: 15–40
P4: 6.5–12		P10: 275–500	P5: 38–82
P5: 12–25		P11: >500	P6: 84–200
			P7: 110–900

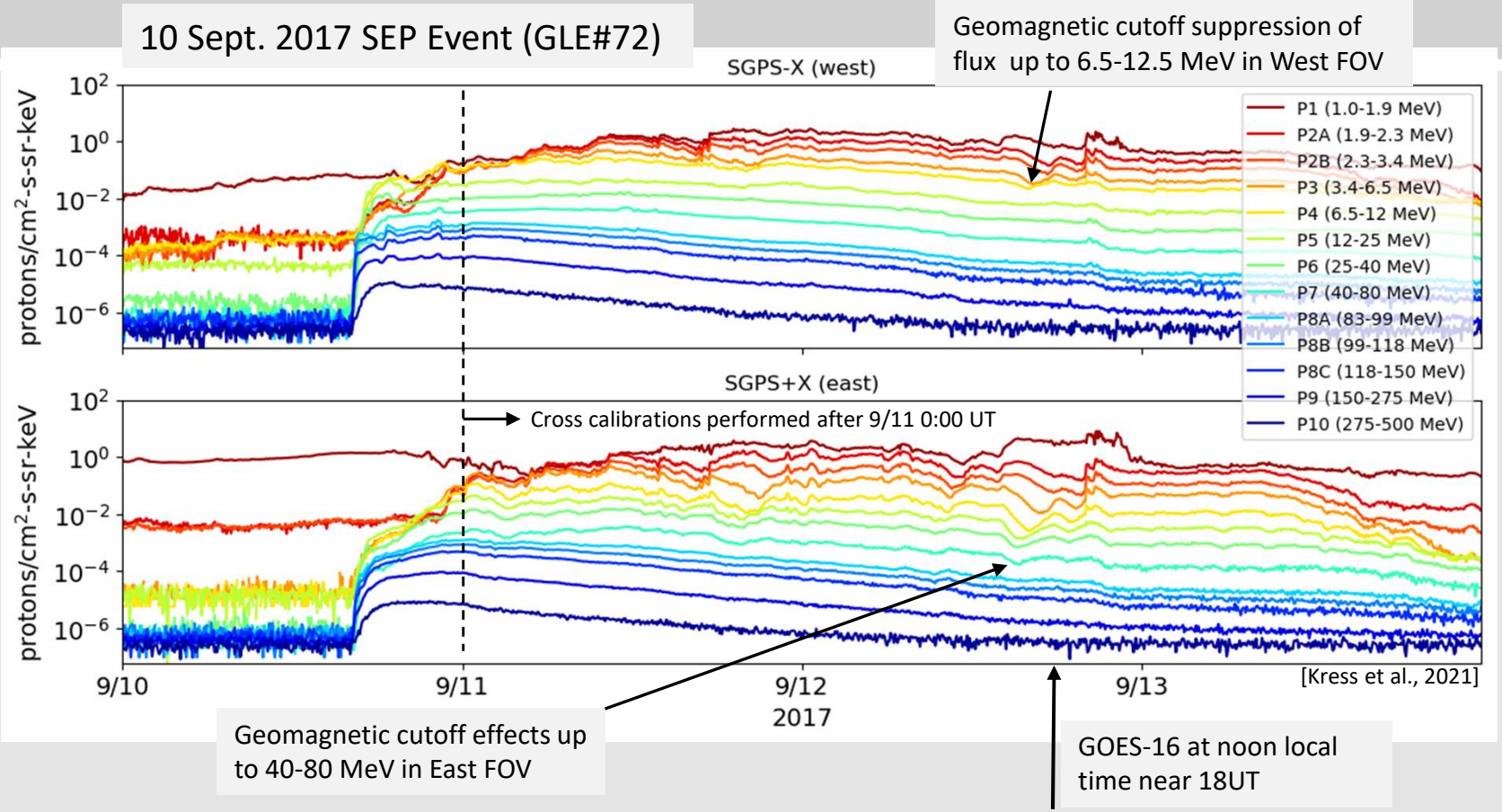
GOES 13-15 (and earlier) EPS channels shown in right column for reference, derived from cross calibrations with SEPEM energies [Sandberg et al., 2014].

SEISS SGPS designed, built, and calibrated by Assurance Technology Corporation

Start of data collection
GOES-16: 8 Jan. 2017
GOES-17: 24 April 2018
GOES-18: 25 April 2022
GOES-19 will launch in 2024

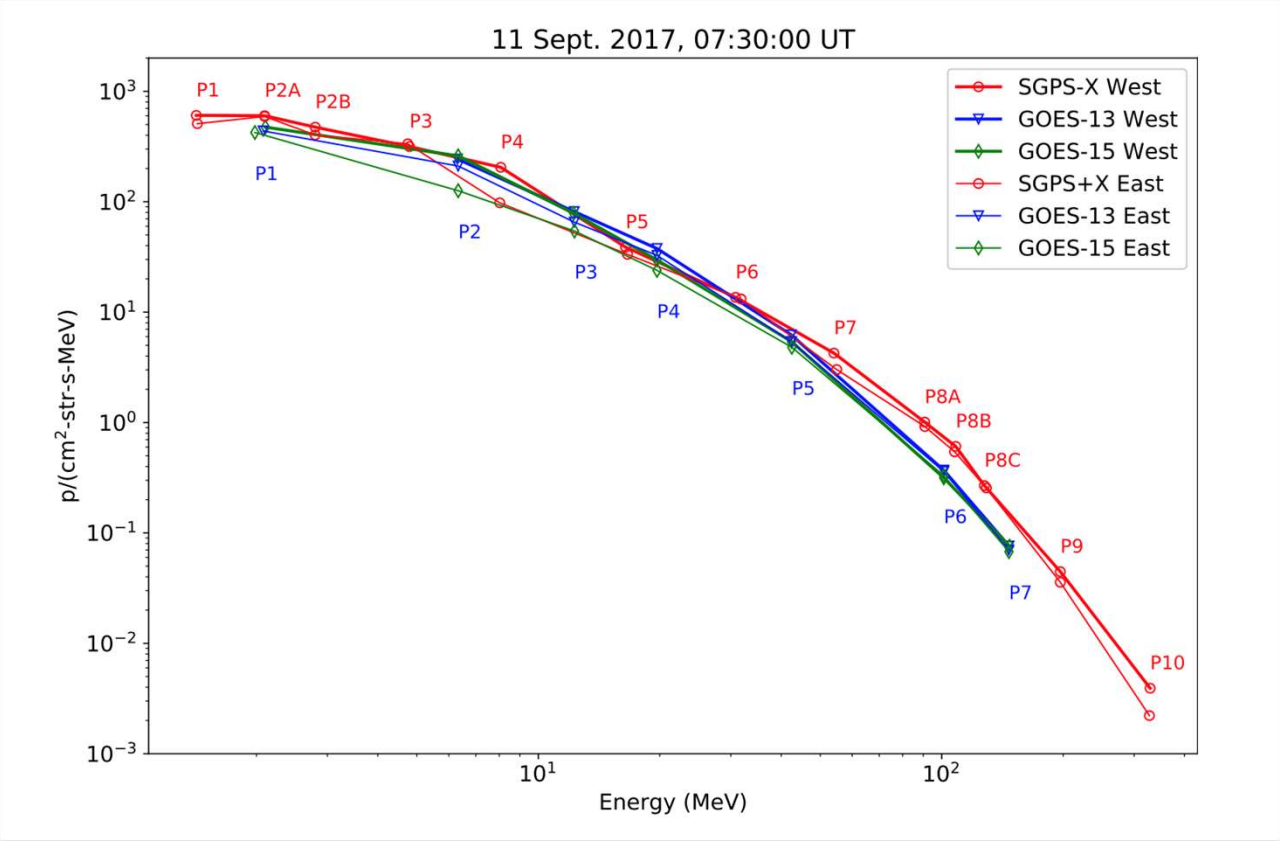
Data available at:
https://www.ncei.noaa.gov/products/satellite/goes-r

SEP cutoffs at geosynchronous in quiet geomagnetic fields



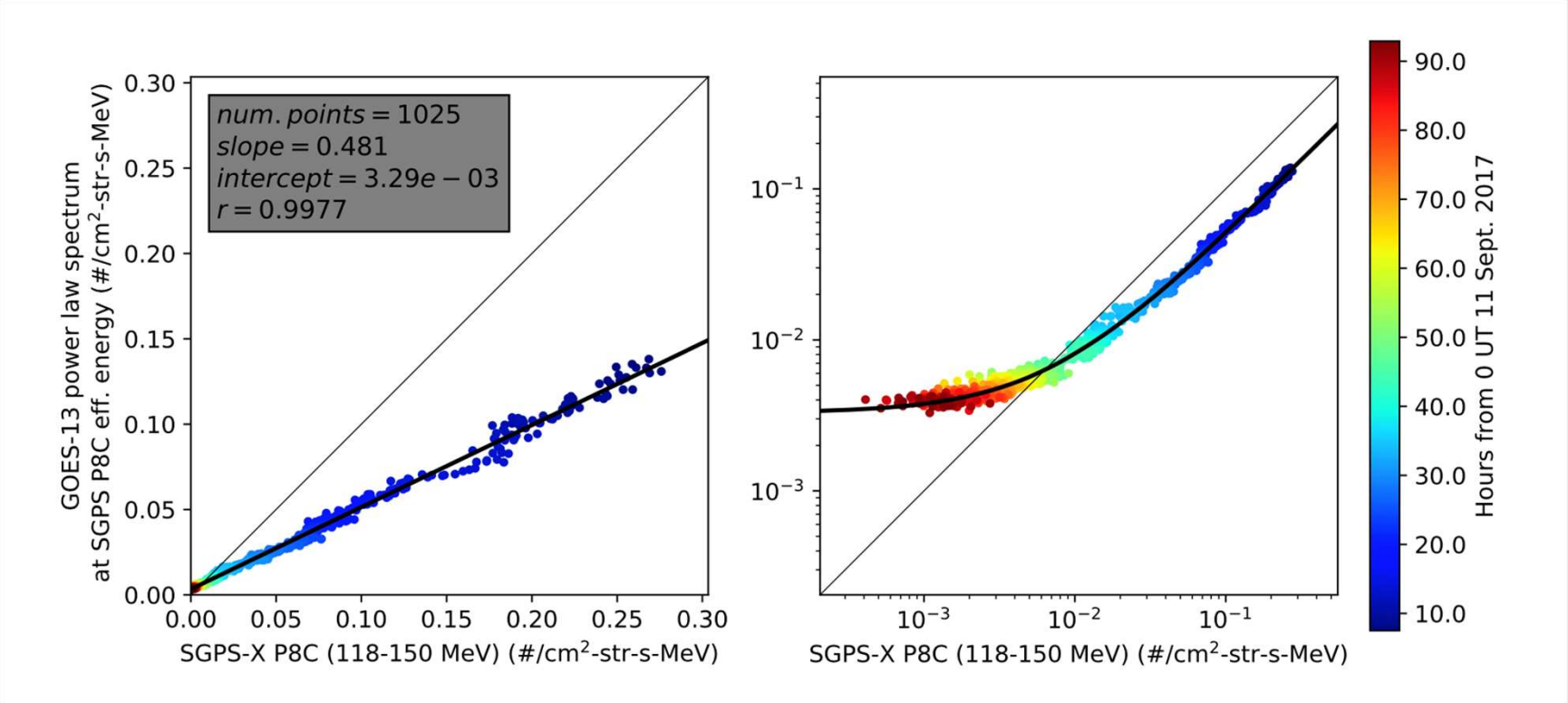
- Note differences between 100s of MeV fluxes in east and west looking fields-of-view near SEP onset. Valid cross comparisons of higher energy channels possible after 2017-09-11 0:00 UT.
- Note cutoff (geomagnetic shielding) effects near noon local time (~18UT) at lower energies.

Comparison of GOES-16 SGPS and legacy GOES-13 & -15 Energetic Particle Sensors (EPSs)



Comparison of spectra from Geostationary Operational Environmental Satellites (GOES)-16 Solar and Galactic Proton Sensor (SGPS), GOES-13 Energetic Particle Sensor (EPS), and GOES-15 EPS at 7:30 UT near the event peak flux during the September 2017 GLE [Kress et al., 2021].

Comparison between GOES-13 EPS and SGPS–X P8C (118-150 MeV)



GOES-13 versus SGPS–X P8C scatter plots of simultaneous 5-min averaged fluxes (both from west looking fields-of-view) from 11 to 15 September 2017 using linear and log scales. A power law is fit to the EPS fluxes, and comparisons with the EPS spectrum are made at SGPS channel effective energies. The same data and OLS fit are shown in both panels [Kress et al., 2021].

* Systematic factor of ≈2 difference between reported SGPS and EPS fluxes over 4-days with high correlation coefficient.

Cross calibration results

Table 2
OLS Fit Parameters From EPS Versus SGPS Scatter Plots of Simultaneous 5-min Averaged Fluxes From 11 to 16 September 2017, Including the Following: Number of Samples, Slope, Intercept, and Correlation Coefficient

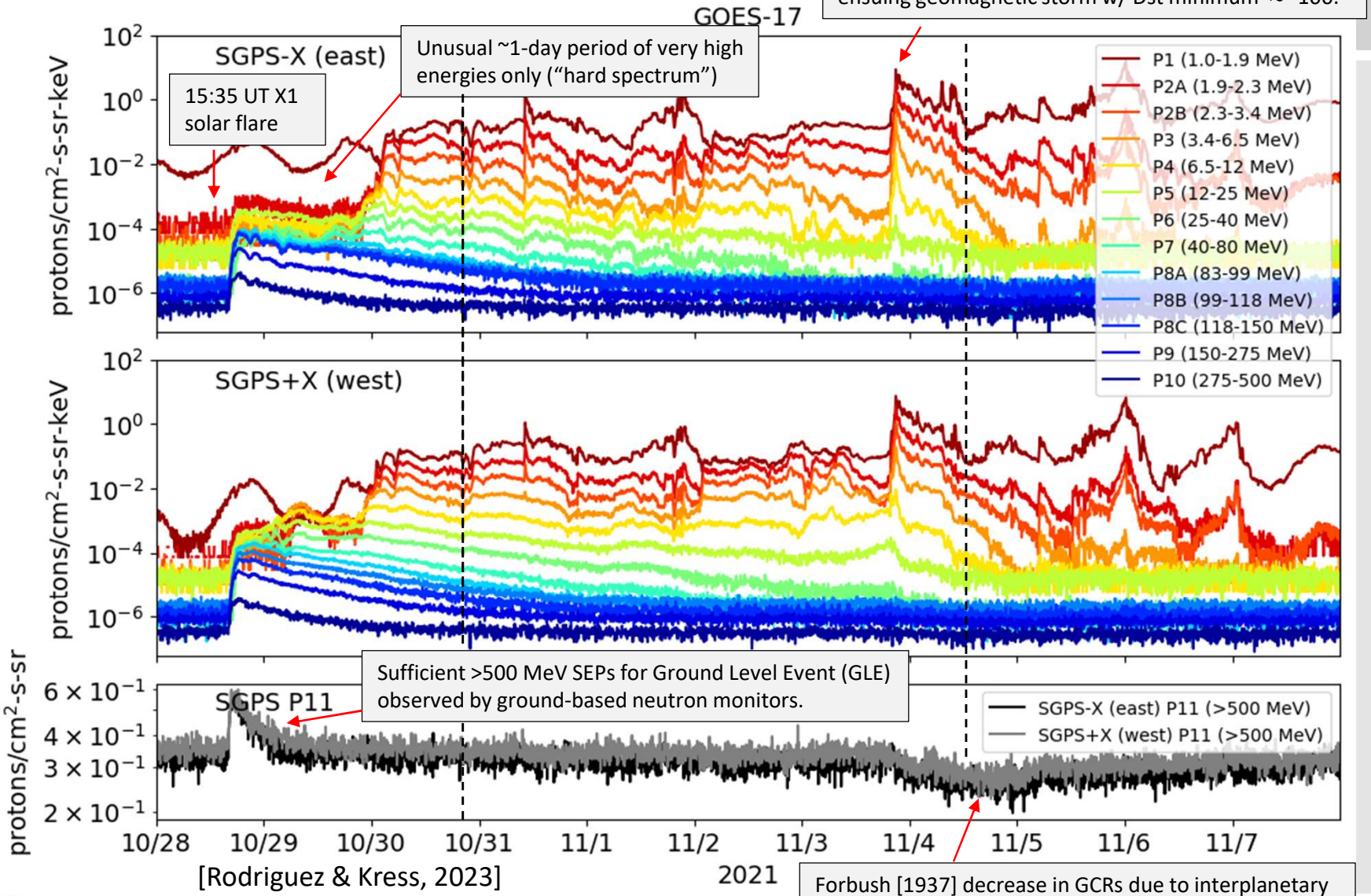
	GOES-13 EPS versus SGPS				GOES-15 EPS versus SGPS			
Channel	Num.	Slope	Intercept	*R*	Num.	Slope	Intercept	*R*
SGPS–X P8A	1,637	0.489	6.26e-03	0.9988	1,637	0.418	5.56e-03	0.9984
SGPS–X P8B	1,431	0.451	4.58e-03	0.9990	1,431	0.397	4.04e-03	0.9988
SGPS–X P8C	1,025	0.481	3.29e-03	0.9977	1,025	0.458	3.07e-03	0.9973
SGPS–X P9	962	0.442	1.15e-03	0.9961	963	0.519	1.28e-03	0.9961
SGPS–X P10	459	0.560	1.36e-04	0.9696	459	0.846	1.82e-04	0.9713
SGPS+X P8A	1,347	0.507	6.53e-03	0.9980	1,347	0.451	5.77e-03	0.9979
SGPS+X P8B	1,319	0.493	4.48e-03	0.9995	1,319	0.449	4.10e-03	0.9995
SGPS+X P8C	1,179	0.461	3.24e-03	0.9991	1,179	0.439	3.11e-03	0.9991
SGPS+X P9	876	0.481	1.07e-03	0.9961	877	0.509	1.14e-03	0.9962
SGPS+X P10	339	0.685	2.85e-05	0.9570	339	0.806	6.04e-05	0.9548

Note. Corresponding plots are included in the supplemental materials.

- Ordinary least squares (OLS) fit to EPS vs. SGPS provides a mapping from SGPS flux to EPS flux (i.e., $j_{EPS} = slope \times j_{SGPS} + intercept$)
- At present, we characterize differences between measurements but do not adjust any geometric factors.
- All Sept. 2017 EPS vs. SGPS scatter plots available from: https://www.ngdc.noaa.gov/stp/space-weather/satellite-data/satellite-systems/goesr/solar_proton_events/sgps_sep2017_event_data/eps_sgps_comparison_plots/

Oct-Nov. 2021 Solar Particle Event (GLE#73)

GOES-17 SGPS 5m Avg. L1b Fluxes



15:35 UT X1 solar flare

Unusual ~1-day period of very high energies only ("hard spectrum")

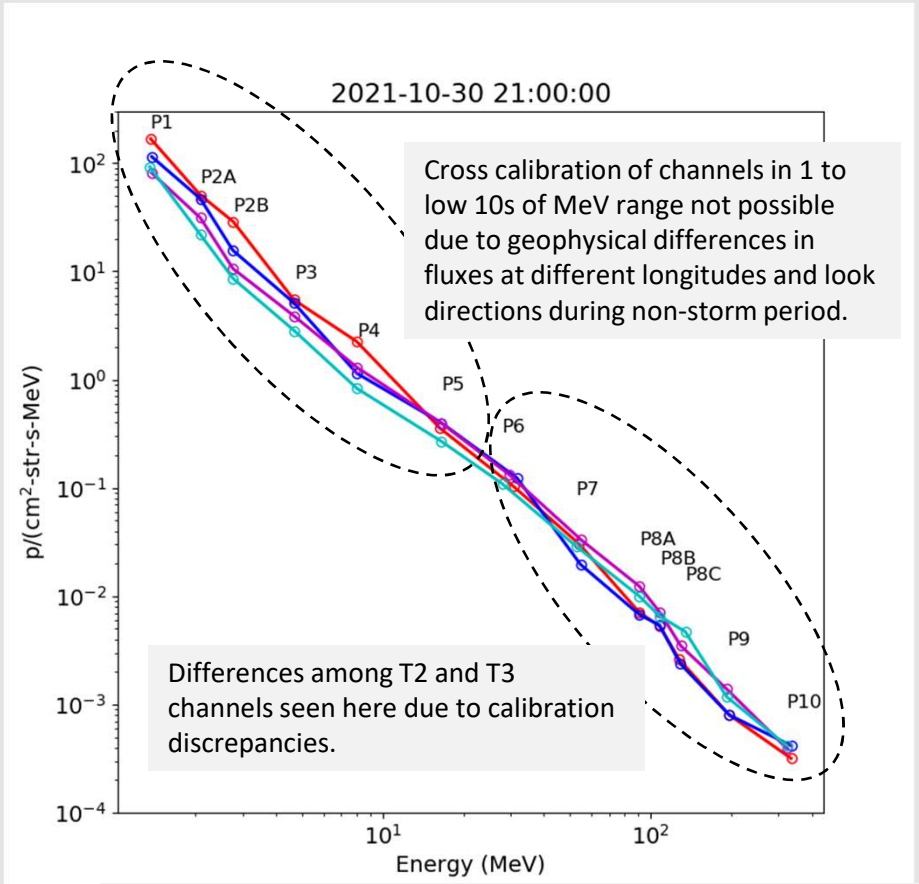
Interplanetary solar wind shock arrival at Earth and ensuing geomagnetic storm w/ Dst minimum ≈ -100.

Sufficient >500 MeV SEPs for Ground Level Event (GLE) observed by ground-based neutron monitors.

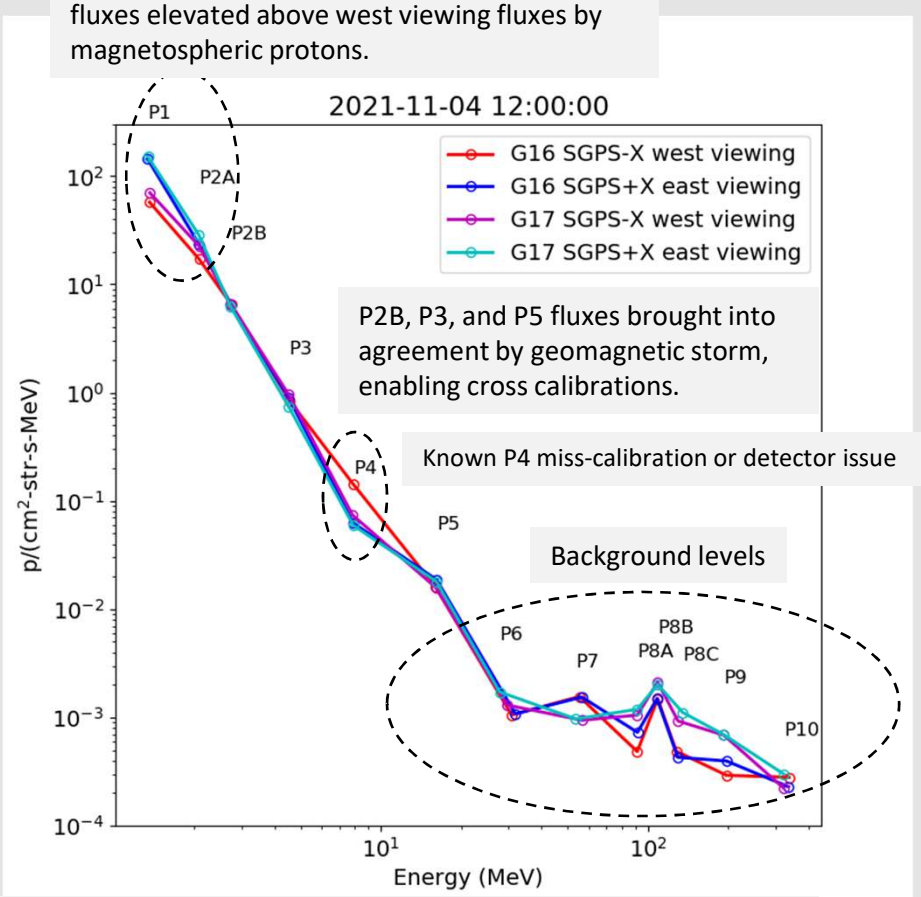
Forbush [1937] decrease in GCRs due to interplanetary solar wind shock propagating outward in heliosphere.

[Rodriguez & Kress, 2023]

Oct-Nov. 2021 Solar Particle Event non-storm vs. storm periods



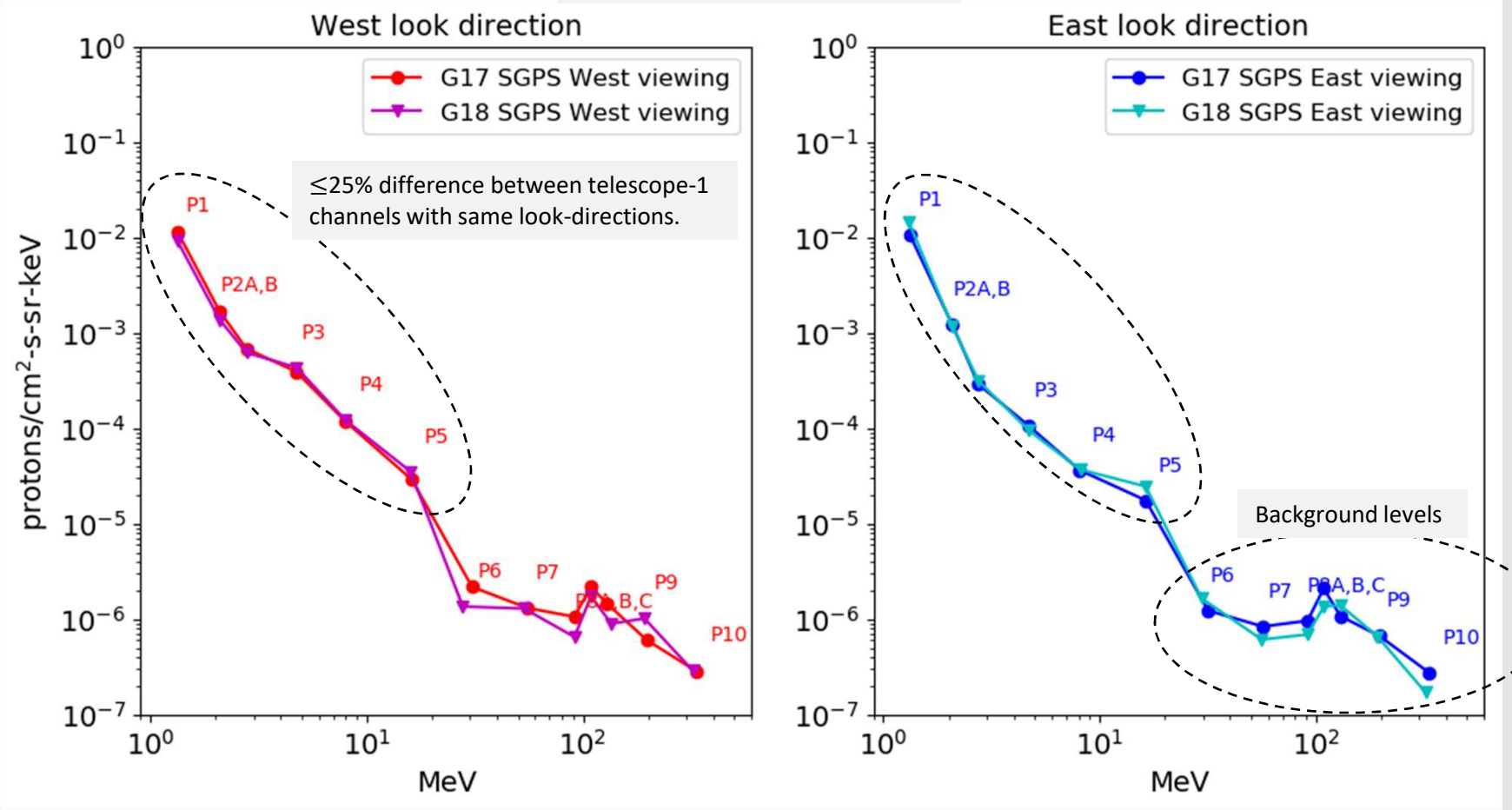
SGPS+X (east looking telescopes) P1 and P2A fluxes elevated above west viewing fluxes by magnetospheric protons.



Comparison of 1-hour averaged spectra from GOES-16 and -17 SGPS east and west looking units (4 sensors) during non-storm (left panel) and storm (right panel) periods, during the Oct-Nov. 2021 ground level SEP event (GLE).

SGPS cross comparisons when GOES-17 and -18 are ≈ 0.4º longitude apart

2022-07-10 18:00:00 UT



Summary

- For on-orbit “cross-calibrations”, differences due to systematic measurement error must be much greater than systematic geophysical differences in fluxes at the detector locations and look-directions compared.
- At present, we characterize discrepancies between channels, but do not adjust geometric factors.
  - When comparing two channels that are expected to report the same flux level, it is not always known which measurement is more accurate.
  - After GOES-19 launch, when there are 6 SGPS units on orbit, some geometric factors may be adjusted to bring outliers into better agreement with like channels on other units.
  - In this case, NCEI will reprocess data with updated geometric factors and make new datasets publically available.
- Since ~1-2 MeV magnetospheric protons have significant local-time and directional dependences, on-orbit cross-calibrations of SGPS P1 and P2A channels are not possible unless two SGPS units are in close proximity ($\lesssim 5^{\circ}$ longitude), or, long-term statistics of geomagnetically identical measurements can be compared.
- Cross calibration of $\gtrsim$40-80 MeV channels is possible when the interplanetary SEP distribution becomes isotropic and homogeneous (usually near and after event peak flux).
- Geomagnetically disturbed periods enable cross calibration of $\gtrsim$2 MeV proton channels.
- Cross calibrations between SEP channels is considered on a case-by-case basis. Comparisons between all channels not always possible.

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