Solar Energetic Particle Measurements Intercalibration Workshop: Today’s Topics and Long-term Goals

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April 11, 2014

Solar Energetic Particle Measurements
Intercalibration Workshop

1:30-6:00 PM in the Millennium Room

50% presentations, 50% discussion

10 planned presentations

Walk-ons welcome: 1-2 charts

Goals of the Workshop

Coordination Group for Meteorological Satellites (CGMS) Objective No. 5 for Space Weather (Geneva, January 2014):
Fostering orbit coordination, on-orbit sensor calibration and harmonization of operational Space Weather sensors and data formats with a view to ensure interoperability and data consistency

- Vision: a consistent international scale for solar energetic particle (SEP) space weather alerts
- Plans for this workshop:
  - Discuss the intercalibration of SEP measurements
  - Foster new intercalibration efforts
  - Recommend a path forward for establishing a set of guidelines for SEP intercalibration

Suggested Workshop Topics

- Operational and scientific needs for relative and absolute accuracy in SEP measurements
- Performance comparisons (past, ongoing, and planned)
- Differences observed in on-orbit comparisons and their possible causes
- Calibrations (beam measurements and simulations) performed prior to launch
- Methods for estimating energy spectra from measurements with broad spectral responses and cross-species contamination, and
- Candidate(s) for “standard” measurement(s) to which to relate other measurements.

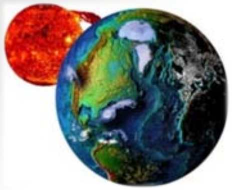
Strawman Guidelines for SEP Intercalibration (1 of 2)

- Relate count rates to differential directional flux (COSPAR PRBEM FPDU or FIDU, $\mathrm{MeV^{-1}\,cm^{-2}\,s^{-1}\,sr^{-1}}$)

$$R = \iint j(E,\Omega) A(E,\Omega)\, d\Omega dE$$

- Start with an understanding of the instrument response from beam calibrations and modeling (Geant4, FLUKA)
  - Expect surprises on orbit
- Different instruments have different strengths – take advantage of them
  - Energy and angular resolution, linearity, dynamic range…

Successful intercalibration requires an understanding of the instruments and the physics of the particles being measured.



Strawman Guidelines for SEP Intercalibration (2 of 2)

- Account for finite instrumental energy and angular responses
  - Beware sensitivity of channel effective energy to spectrum being measured
- Understand instrument nonlinearities
  - Beware effects of dead time and saturation
- Account for radiation that penetrates the sides
  - Galactic cosmic rays, highly-energetic SEPs (ground level enhancements, GLEs)
- Observe the same fluxes
  - Beware transport effects: anisotropies, geomagnetic cutoffs
  - Overlap between different series may be poor

Successful intercalibration requires an understanding of the instruments and the physics of the particles being measured.

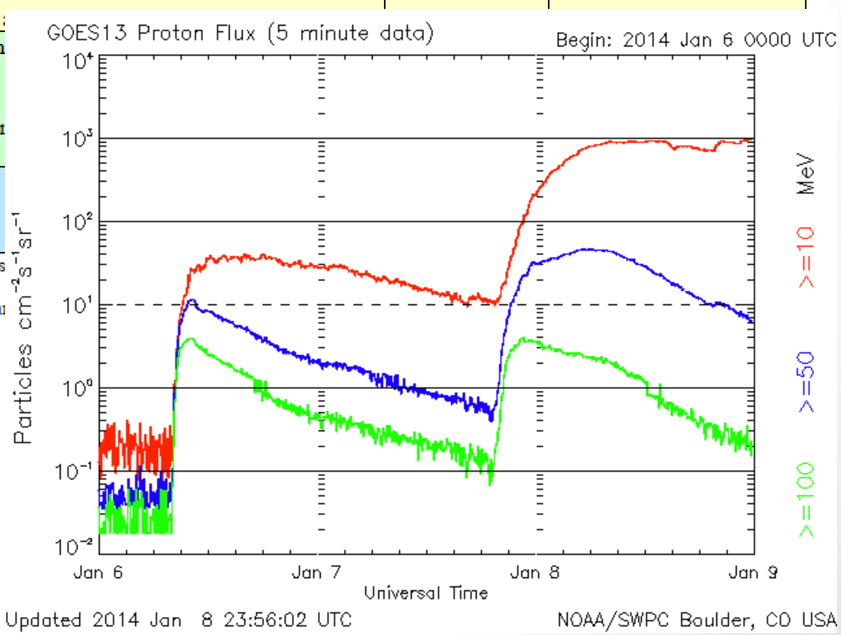
Intercalibration Example: GOES 8-15 Energetic Particle Sensors (EPS)

Solar Radiation Storms			Flux level of ≥ 10 MeV particles (ions)*	Number of events when flux level was met**
S 5	Extreme	Biological: unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. *** Satellite operations: satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. Other systems: complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle
S 4	Severe	Biological: unavoidable radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: may experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. Other systems: blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.	10^4	3 per cycle
S 3	Strong	Biological: radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. Other systems: degraded HF radio propagation through the polar regions a	10^3	10 per cycle
S 2	Moderate	Biological: passengers and crew in high-flying aircraft at high latitudes m risk.*** Satellite operations: infrequent single-event upsets possible. Other systems: effects on HF propagation through the polar regions, and r possibly affected.		
S1	Minor	Biological: none. Satellite operations: none. Other systems: minor impacts on HF radio in the polar regions.		

* Flux levels are 5 minute averages. Flux in particles·s^{-1}·ster^{-1}·cm^{-2} Based on this measure, but other physical measures

** These events can last more than one day.

*** High energy particle (>100 MeV) are a better indicator of radiation risk to passenger and crews. Pregnant women ar



Integral fluxes derived from EPS data are used by SWPC to characterize Solar Radiation Storms in real time

Intercalibration Example: GOES 8-15 Energetic Particle Sensors (EPS)

- SMS 1-2, GOES 1 (1974)
- GOES 2-3 (1977)
- GOES 4-7 (1980)
- GOES 8-12 (1994)
- GOES 13-15 (2006)
- GOES R, S, T, U (2016)

Energies: **one change (P4)**
Orientation: **from spin-averaged to west-facing**
SEP Overlap: **1 event (Oct. 1995)**

Energies: **no change**
Orientation: **east- & west-facing**
SEP Overlap: **2 events (Dec. 2006)**

Energies: **new set of channels**
Orientation: **east- & west-facing**
SEP Overlap: **??**

Intercalibration Example: GOES 8-15 Energetic Particle Sensors (EPS)

$$R = \iint j(E,\Omega) \underbrace{A(E,\Omega)} \, d\Omega dE$$

- Effective area measured at multiple energies and angles and compared with analytical models (1970's-1980's)
- Instrument design has not changed since GOES-8
- Similar energy and angular responses
- Similar (small) non-linearities
- Similar response to penetrating radiation
- **CHALLENGE: identifying when different EPSs are observing same fluxes**
  - **Two look directions: facing east and west in the orbital plane**
  - **Geomagnetic cutoffs affect east-facing more than west-facing**

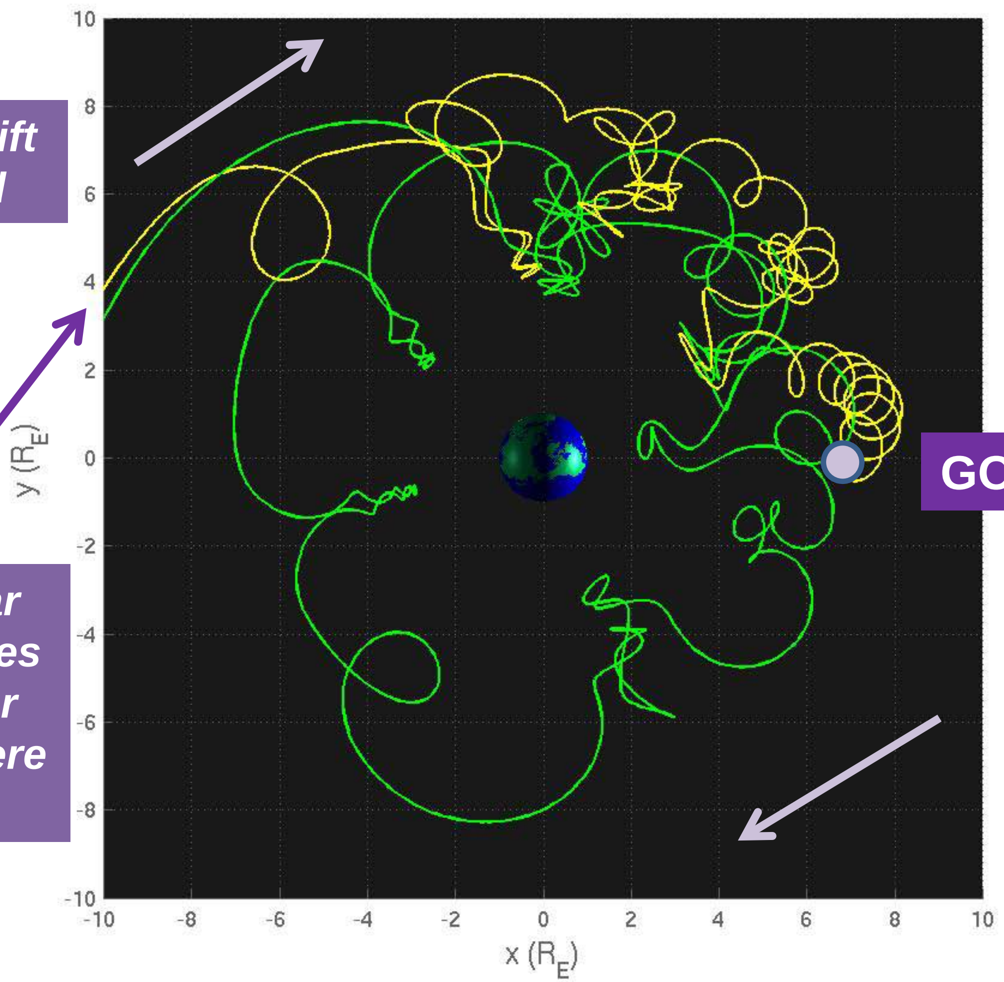
GOES is not an interplanetary mission!

SEP trajectories in the magnetosphere can be complex near geomagnetic cutoffs

Lorentz trajectories in TS05 (quiet: Bz = +5 nT, Pdyn = 4 nPa, Dst = 0 nT) projected to XY plane

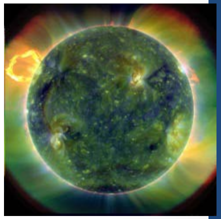
Protons drift westward

Protons near cutoff energies access inner magnetosphere from tail



GOES

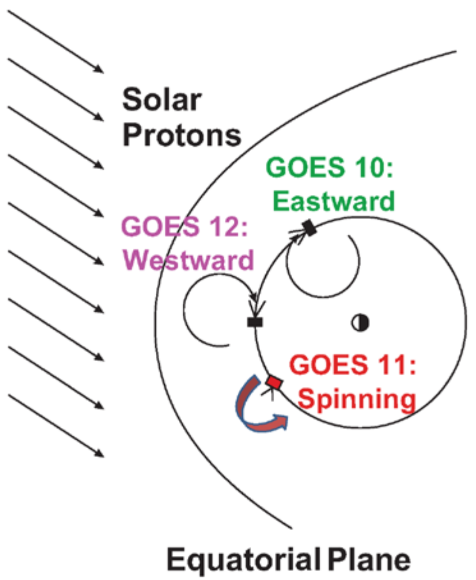
10 MeV proton reaches West FOV: outer trajectory

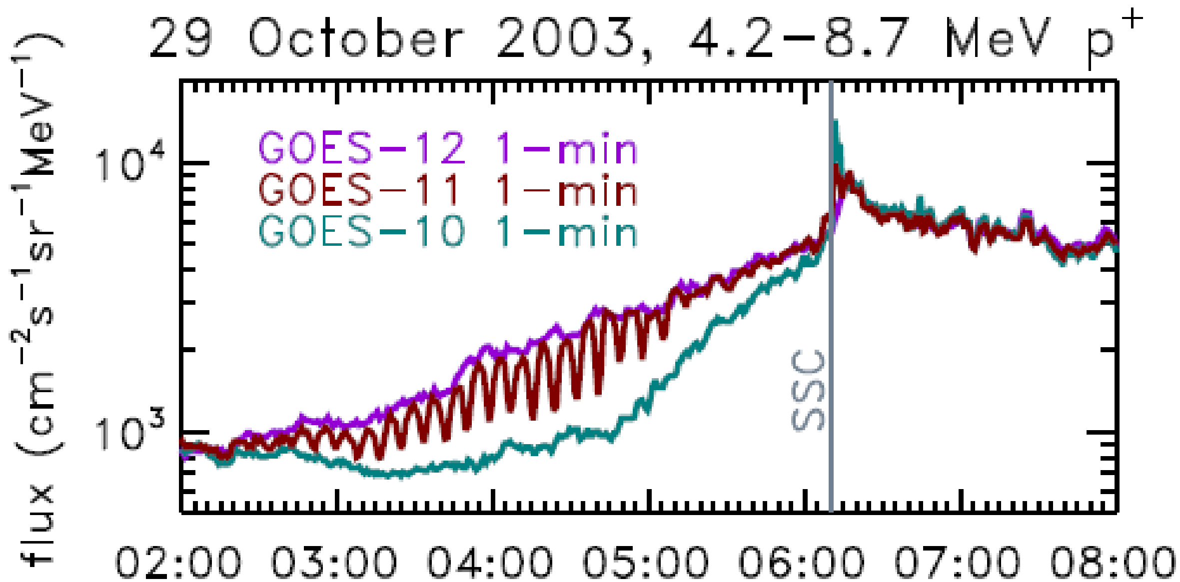


50 MeV proton reaches East FOV: inner trajectory

Courtesy Brian Kress; method of Kress et al. (2010)

Increased solar wind dynamic pressure enhances SEP access to GEO





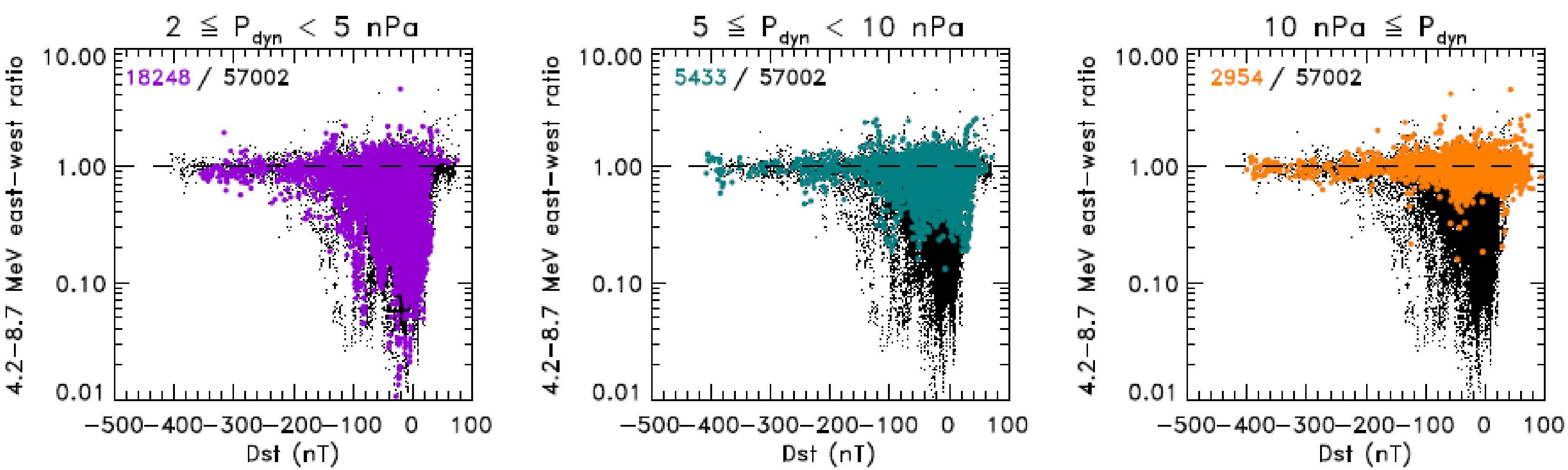
Spinning (GOES-11) and eastward (GOES-10) observations attenuated

Shock arrives; solar wind pressure increases

All GOES observe the same fluxes; P_{dyn} (He) ~ 10 nPa

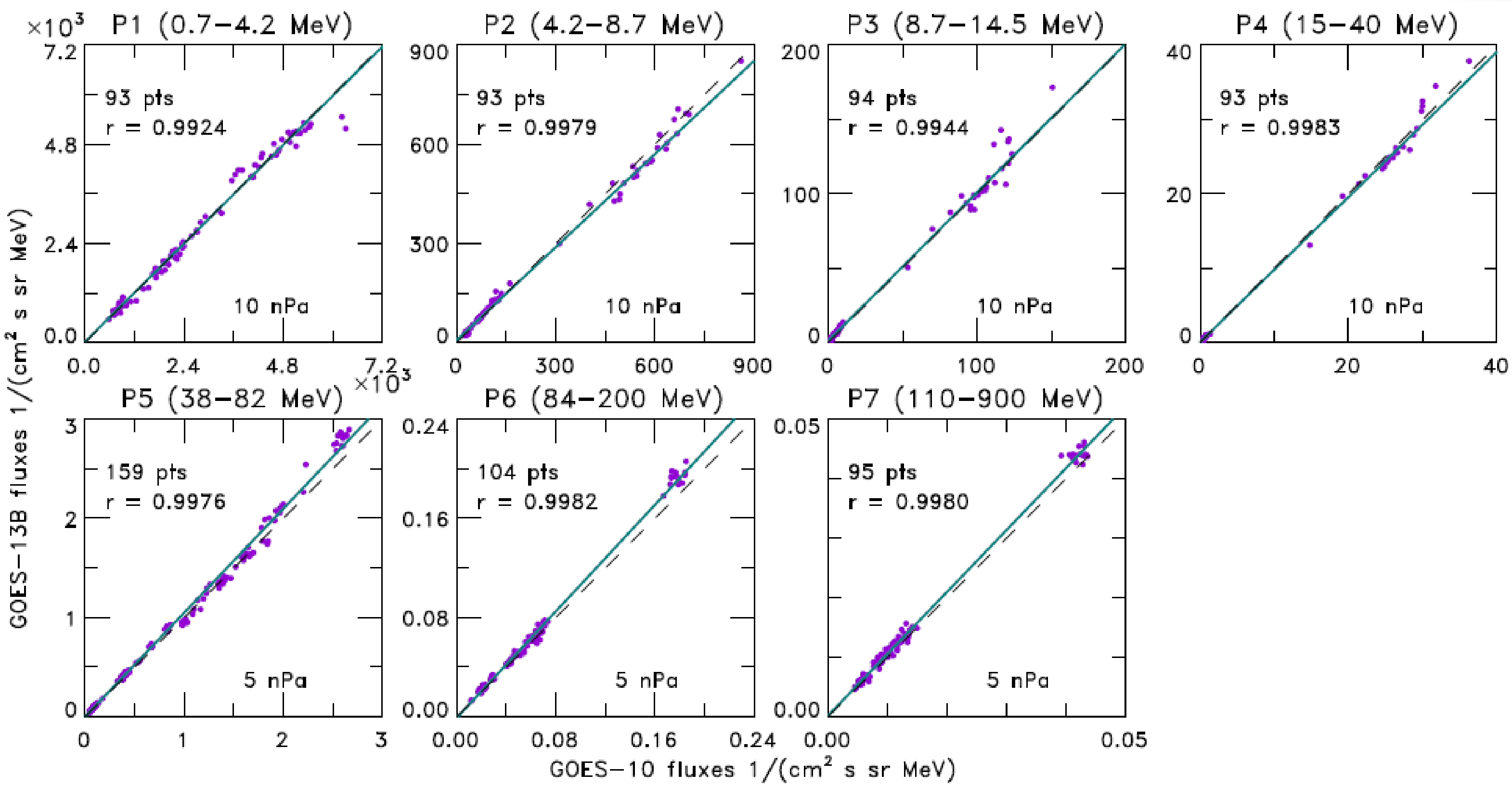
Cutoffs strongly suppressed when P_{dyn} > 10 nPa: intercalibrate!

Two EPS facing east and west observe similar fluxes for $P_{dyn} \geq 10$ nPa



- Scatter plots of east-west ratios of GOES EPS channel P2 (4.2–8.7 MeV) as a function of USGS *Dst* from April 1998 to December 2006
  - Lowest energy GOES SEP channel that does not also observe trapped radiation belt protons
  - Most affected by geomagnetic fields (cutoffs)
- All GOES channels <40 MeV are sensitive to cutoffs and benefit from this intercalibration criterion

GOES 8-15 and 13-15 series intercalibrated using December 2006 SEP events



Agreement is good (within 20%) among the GOES 8-15 EPS, and between the GOES 8-12 and 13-15 series built years apart.

Rodriguez et al., *Space Weather, 12*, 92–109, 2014

This research has been supported by NSF National Space Weather Program awards AGS-1024701 and AGS-1023339.

Workshop Agenda (1 of 2)

- Drivers for intercalibration (operational, scientific)
- Comparisons with GOES
  - Jiggens and Sandberg: Calibration of SEP measurements as part of the SEPEM project
  - Armstrong: Intercalibration challenges
  - Li et al.: Cross-comparison of energetic particle data between Fengyun and NOAA satellites
  - Podzolko and Kalegaev: Problems of reliability of the SEP data; SEP measurements on Electro-L
- Recent and Future Missions
  - Mazur et al.: Van Allen Probes REPT and RPS, CRaTER and GOES
  - Jaynes et al.: Van Allen Probes REPT, GOES and ACE

Workshop Agenda (2 of 2)

- Recent and Future Missions
  - Schiller et al.: Colorado Student Space Weather Experiment (CSSWE) observations of SEPs
  - Nagatsuma: Proton instruments on GMS-8 and -9
- Data Services
  - Cooper: Virtual Energetic Particle Observatory (VEPO)
  - Heynderickx: SEPServer
- The Path Forward
  - Recommendations for intercalibration approaches (discussion)
  - Candidate events for intercalibration (discussion)

See you at 1:30 in the Millennium Room! (e-mail me your presentations)

- With international organizations such as CGMS turning their attention to space weather observations, the time is opportune for a workshop on the intercalibration of solar energetic particle (SEP) measurements.
- With the assembled group, we can take advantage of many years of experience in this area to recommend a path forward for establishing a set of guidelines for SEP intercalibration
- This will strengthen the science and enable a consistent international scale for SEP space weather alerts
- Future workshops?
  - Radiation belt particles
  - Magnetic fields