Intercalibration of the Solar Proton Channels from the GOES 8-15 Energetic Particle Sensors

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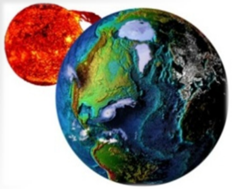


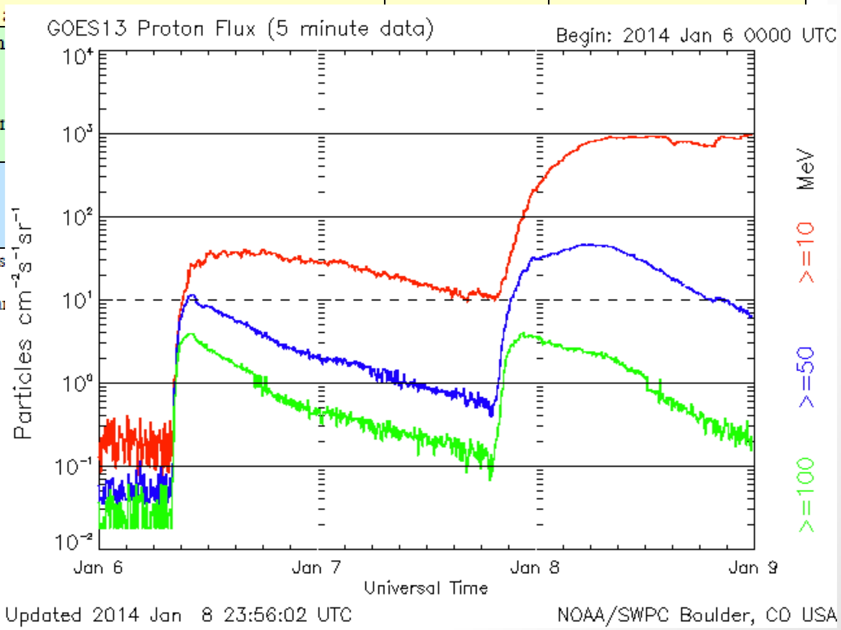
GOES 8-15 Energetic Particle Sensors (EPS): Basis for SWPC Solar Radiation Storm Alerts

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	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 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 a



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

GOES 8-15 Energetic Particle Sensors (EPS): Measurement Equation

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

- 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 two EPS instruments are observing same fluxes**
  - **Two look directions: facing east and west in the orbital plane**
  - **Geomagnetic cutoffs are higher east-facing than west-facing**

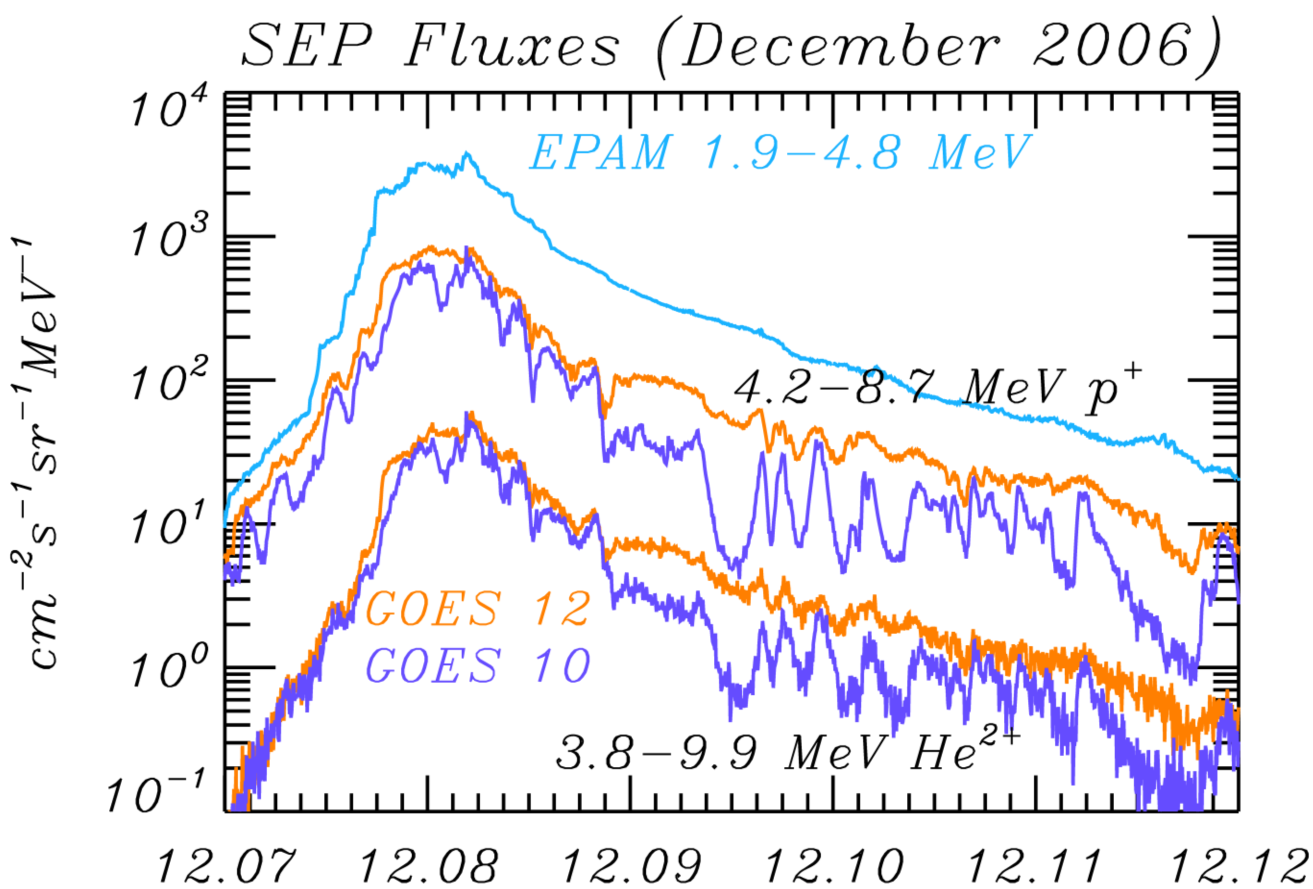
GOES is not an interplanetary mission!

Solar proton fluxes observed eastward are lower than those observed westward at GEO

EPAM on ACE at L1

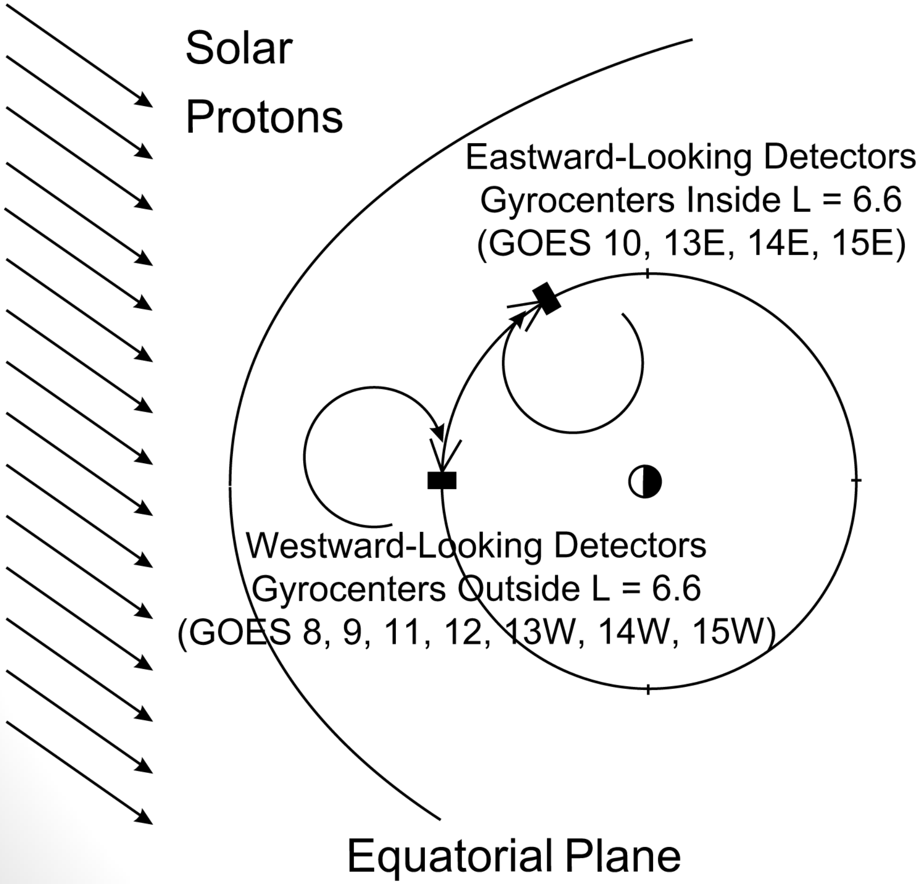
GOES 12 detector looking westward

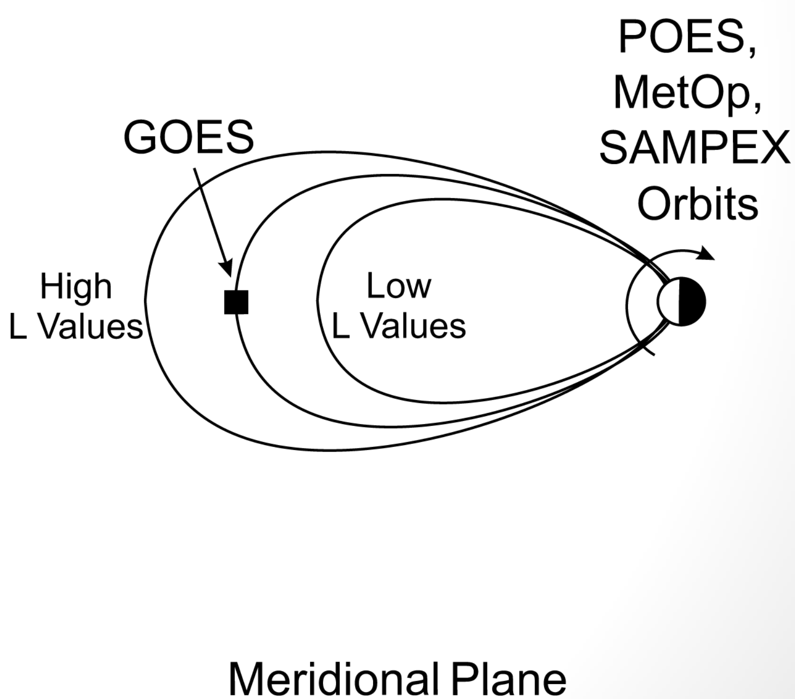
GOES 10 detector looking eastward



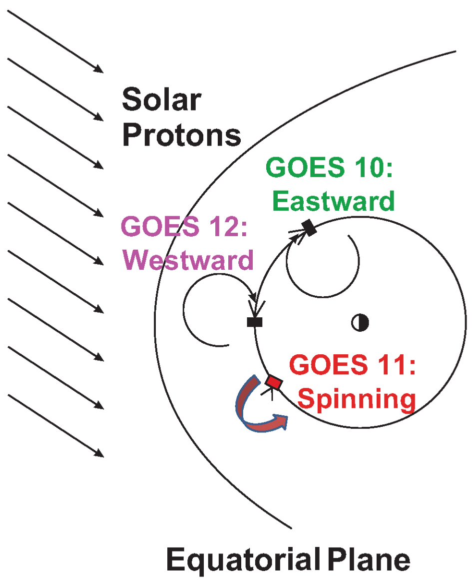
East-west differences are consequences of a large proton gyroradius and a *radial* flux gradient

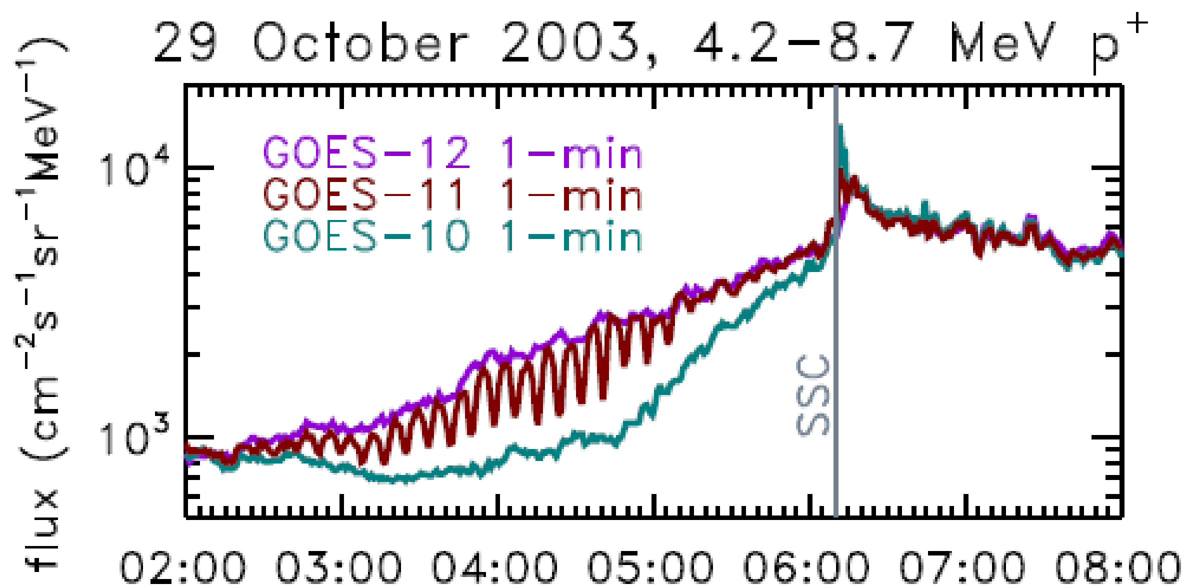
In a 100 nT magnetic field, 1-100 MeV protons have 0.2-2 R_e gyroradii at 90 deg pitch angle





Increased solar wind dynamic pressure enhances SEP access to GEO, modifies radial gradient





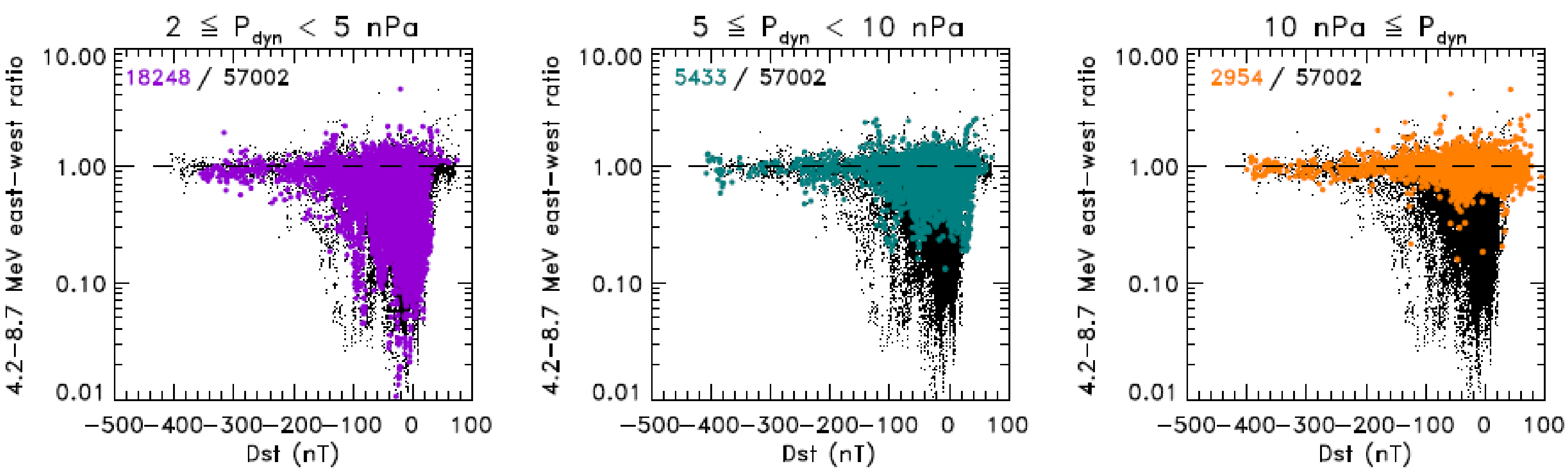
Spinning (GOES-11) and eastward (GOES-10) observations attenuated

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

Shock arrives; solar wind pressure increases

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

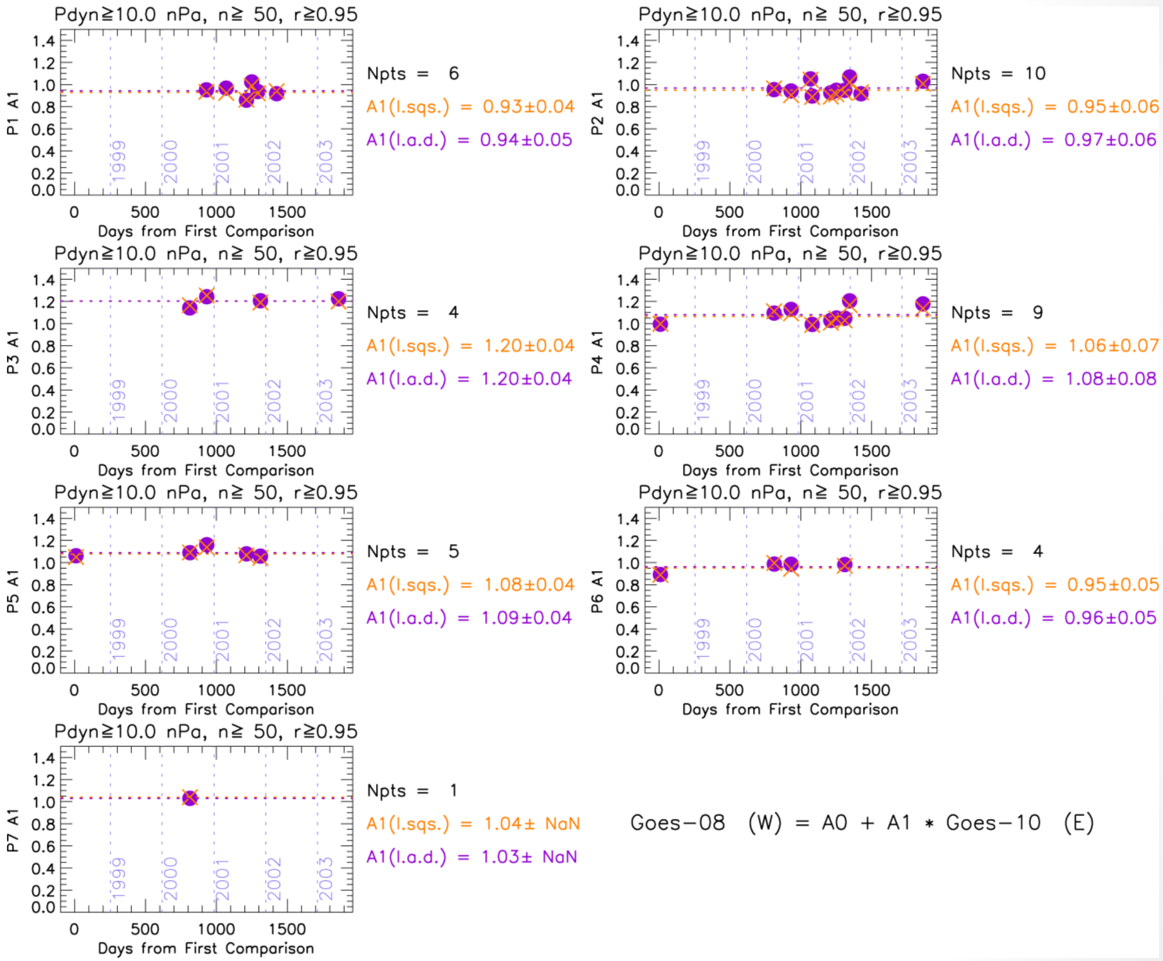
Instruments facing east and west observe similar fluxes for $P_{dyn} \geq 10$ nPa



- 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
  - P2 is the 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

Multiple events are aggregated in order to improve the intercalibrations

- Intercalibration rarely satisfactory with individual events
  - All energies, dynamic range not covered with P_{dyn} restricted to large values
- Example: GOES-8 to GOES-10 comparisons
  - Number of points in each event ≥ 50
  - Linear correlation coefficient r ≥ 0.95 in each event
  - No significant trend over shared mission lifetimes



Conclusion: need to aggregate observations over shared mission lifetimes of two satellites in order to achieve a good intercalibration

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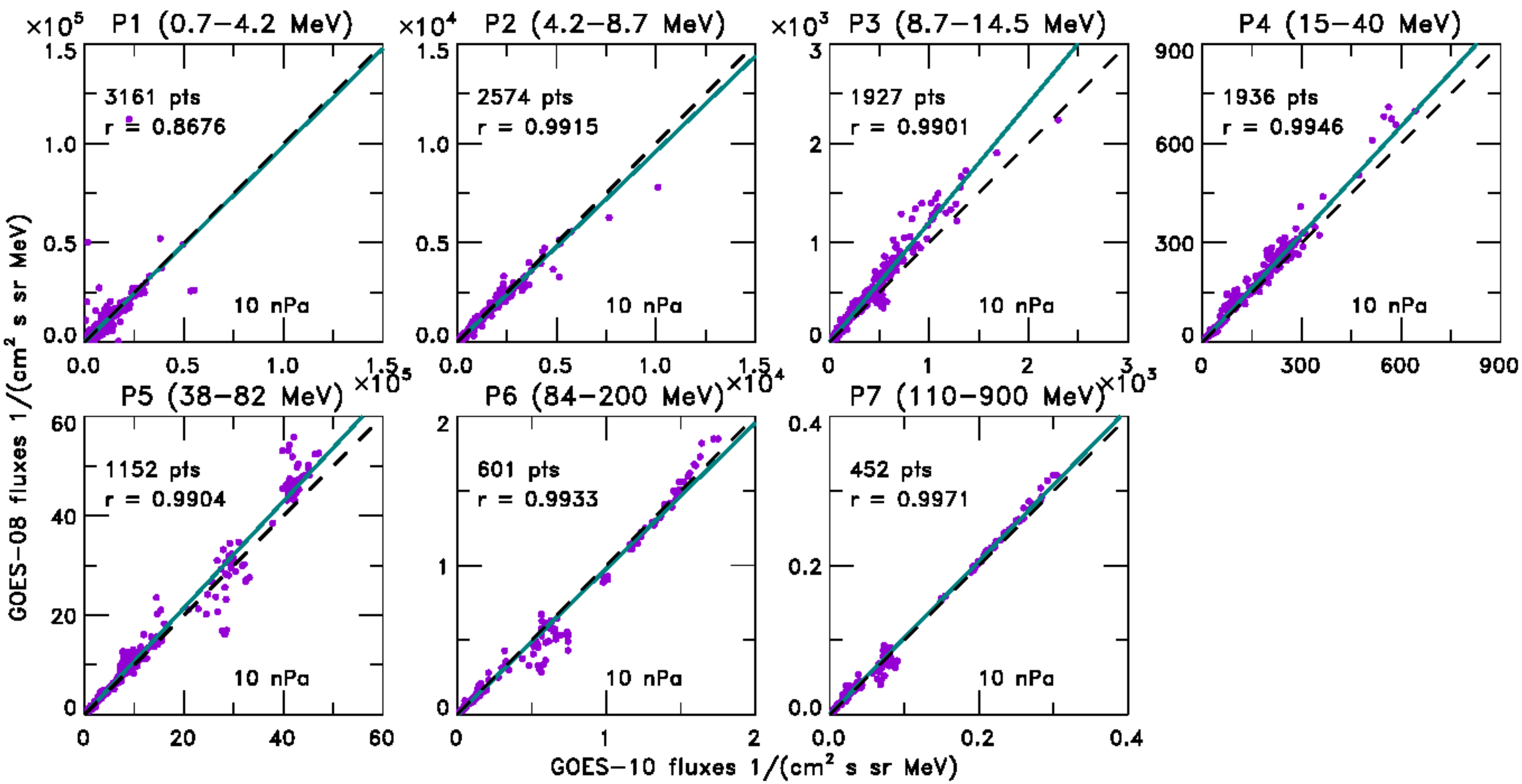
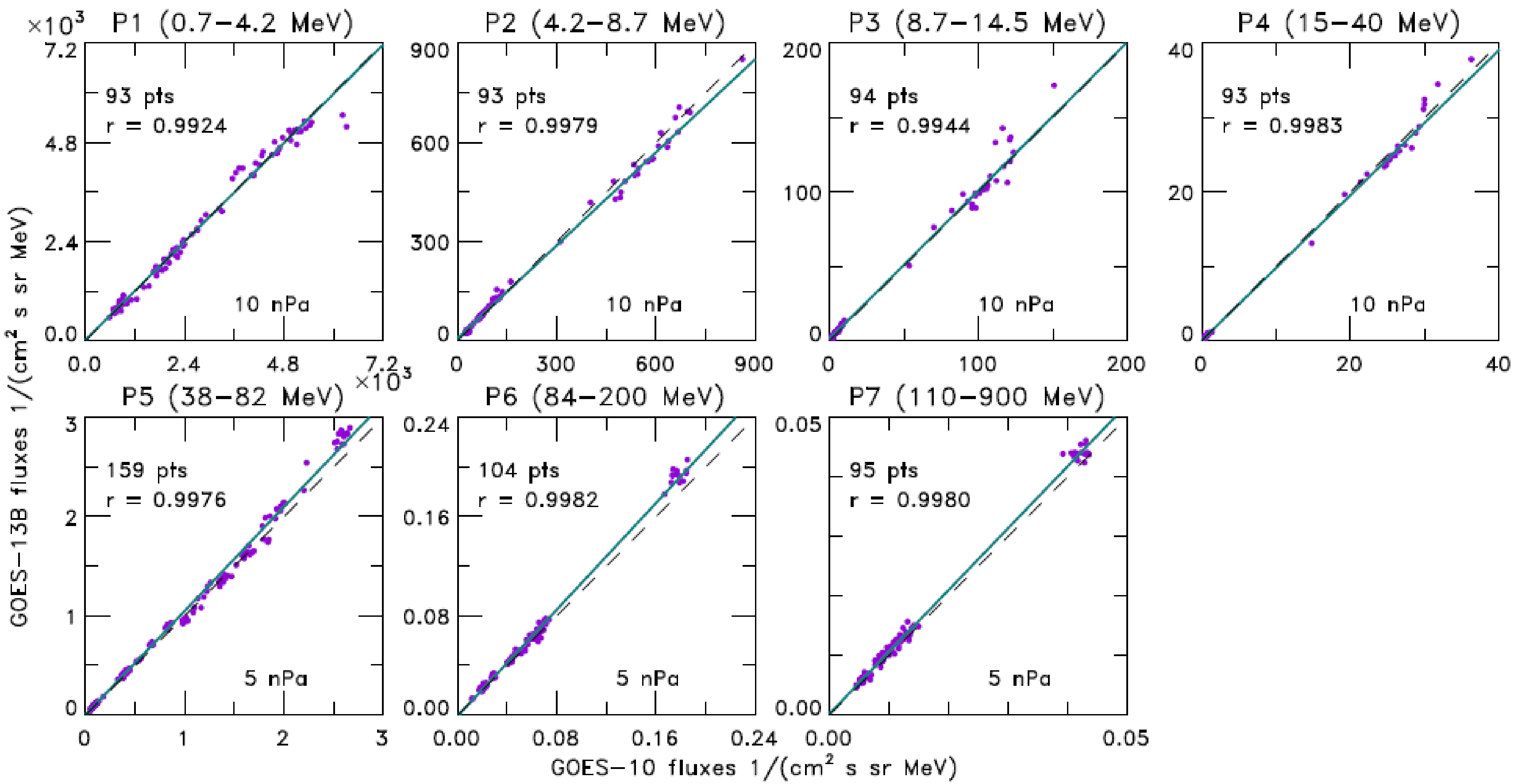
GOES-8 (westward) and GOES-10 (eastward) intercalibrated for Pdyn > 10 nPa



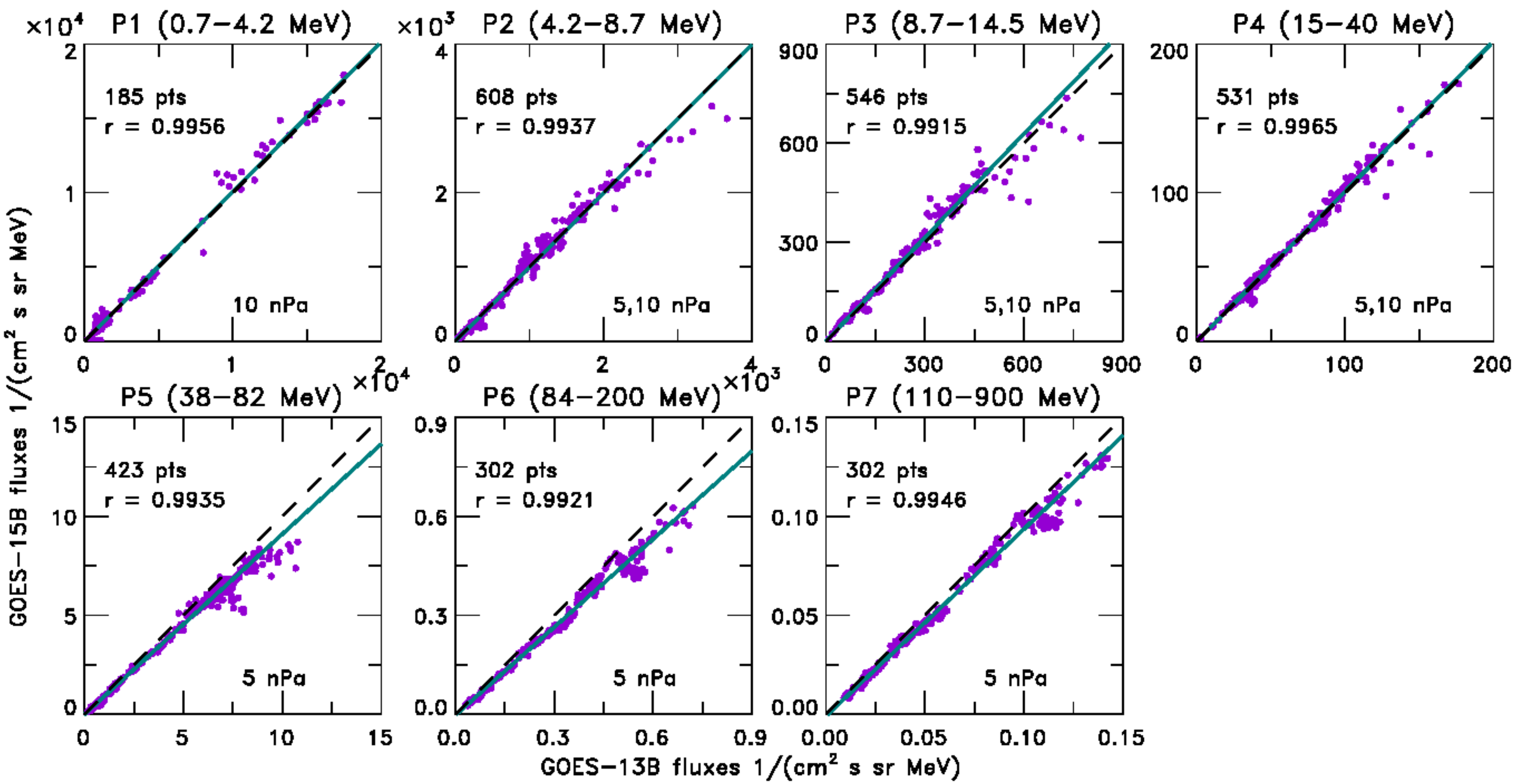
GOES-8 overlapped with GOES-9, -10, -11 and -12 EPS, provides best benchmark since looked westward

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



Example: GOES-13B vs. GOES-10

GOES-13B (westward) and GOES-15B (eastward and westward) intercalibrated 2012-2013



5 nPa criterion used when G13B and G15B both looked westward

GOES intercalibration differences have a <10% effect on derived proton integral fluxes

Energy (MeV)	>1	>5	>10	>30	>50	>60	>100
RMS error, fractional							
14–15 July 2000	0.037	0.057	0.093	0.016	0.071	0.043	0.013
28–30 October 2003	0.025	0.038	0.092	0.018	0.070	0.041	0.012

[a]The examples used are the Bastille Day 2000 and Halloween 2003 SEP events.

RMS Error Between GOES-11 Integral Fluxes Calculated from Original Channel Fluxes and from Channel Fluxes Adjusted to GOES-8 Levels using Intercalibration Results

Summary

- Conditions for accurate intercalibration of solar proton flux observations in geostationary orbit:
  - Pdyn > 10 nPa when intercalibrating east-east, east-west, west-north, etc.
  - Pdyn > 5 nPa when intercalibrating west-west
- Apart from lowest energy channel (P1), which includes trapped ring current fluxes, these conditions result in $r^2 \geq 0.95$ for all comparisons (except G9 vs. G10 P7: $r^2 = 0.85$)
- Agreement is good (within 20%) among the GOES 8-15 EPS
  - Consistency: GOES 8-12 and 13-15 series built years apart
- For details of the analysis, please see Rodriguez et al. (2014), *Space Weather, 12,* 92-109

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