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**

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

<table>
<thead>
<tr>
<th>Solar Radiation Storms</th>
<th>Flux level of ≥ 10 MeV particles (ions)</th>
<th>Number of events when flux level was met**</th>
</tr>
</thead>
<tbody>
<tr>
<td>S5 Extreme</td>
<td>10⁷</td>
<td>Fewer than 1 per cycle</td>
</tr>
<tr>
<td>S4 Severe</td>
<td>10⁴</td>
<td>3 per cycle</td>
</tr>
<tr>
<td>S3 Strong</td>
<td>10³</td>
<td>10 per cycle</td>
</tr>
<tr>
<td>S2 Moderate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1 Minor</td>
<td></td>
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</tbody>
</table>

**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:** 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.

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*Flux levels are 5 minute averages. Flux in particles cm⁻² ster⁻¹ cm². Based on this measure, but other physical measures may be used.*

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

\[ R = \int\int j(E, \Omega) A(E, \Omega) \, d\Omega \, dE \]

- 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.
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

Shock arrives; solar wind pressure increases

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

Cutoffs strongly suppressed when $P_{\text{dyn}} > 10 \text{ nPa}$: intercalibrate!
Instruments facing east and west observe similar fluxes for \( P_{\text{dyn}} \geq 10 \ nPa \)

- 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 $P_{\text{dyn}}$ restricted to large values
- Example: GOES-8 to GOES-10 comparisons
  - Number of points in each event $\geq 50$
  - Linear correlation coefficient $r \geq 0.95$ 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
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

<table>
<thead>
<tr>
<th>Energy (MeV)</th>
<th>&gt;1</th>
<th>&gt;5</th>
<th>&gt;10</th>
<th>&gt;30</th>
<th>&gt;50</th>
<th>&gt;60</th>
<th>&gt;100</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS error, fractional</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14–15 July 2000</td>
<td>0.037</td>
<td>0.057</td>
<td>0.093</td>
<td>0.016</td>
<td>0.071</td>
<td>0.043</td>
<td>0.013</td>
</tr>
<tr>
<td>28–30 October 2003</td>
<td>0.025</td>
<td>0.038</td>
<td>0.092</td>
<td>0.018</td>
<td>0.070</td>
<td>0.041</td>
<td>0.012</td>
</tr>
</tbody>
</table>

The examples used are the Bastille Day 2000 and Halloween 2003 SEP events.
Summary

• Conditions for accurate intercalibration of solar proton flux observations in geostationary orbit:
  • $P_{dyn} > 10 \text{ nPa}$ when intercalibrating east-east, east-west, west-north, etc.
  • $P_{dyn} > 5 \text{ nPa}$ 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

*This research was supported by NSF National Space Weather Program award AGS-1024701 to the University of Colorado and by the NOAA Hollings Scholarship Program.*