NOAA-NCEI Review of "Panel on Radiation Belt Environment Modeling (PRBEM) Data analysis procedure", with respect to GOES particle instrument cross-calibrations and NOAA-NCEI's publicly available space particle data

- Text in quotes is from the PRBEM document.
- NOAA-NCEI considerations are in blue text.
- SGPS: GOES-R series Solar and Galactic Proton Sensor, measures 1-100s of MeV protons.
- MPS-HI: GOES-R series high energy Magnetospheric Particle Sensor, measures fluxes of electrons and protons at radiation belt energies.

III.2 Magnetic field model

"The proposed standard for the magnetic field model is IGRF (decimal year + 0.5) plus Olson-Pfitzer quiet 1977."

From Sect. III.2: "…in-situ radiation-belt particle data are analyzed in order to develop a radiation-belt model." Using O-P quiet '77 for binning particle data for development of radiation-belt models intended to represent long-term average conditions (e.g., AE8) is a good approach. For cross instrument calibrations in a highly variable radiation environment, to isolate discrepancies between measurements, it's best to use the most accurate geomagnetic field model available.

Discrepancies between measurements made at different locations in the magnetosphere, that are L^*-J_2 conjunctions in O-P quiet, will be partly due to differences between the O-P field model and the actual geomagnetic field and partly due to measurement errors. The contribution from inaccuracies in the geomagnetic field model must be quantified. If this contribution dominates over measurement errors, another method for cross-calibrations must be used (e.g., comparing long-term statistical averages over similar orbits). A way to estimate the difference due to inaccuracies in a geomagnetic field model is to repeat cross-calibrations using different geomagnetic field models [e.g., Selesnick and Blake, 2000].

IV.1 Electron data contamination
IV.1.1 Contamination by proton

"It is well known that during times of solar energetic proton events (SEPs) many of the detectors are contaminated with strong background counts."

MPS-HI electron and SGPS proton channel comparisons have exhibited little-to-no contamination of electrons by SEPs.

IV.1.2 Contamination by relativistic electrons

“measurements can be contaminated by Bremsstrahlung photons.”

Bremsstrahlung tails accounted for implicitly in the MPS-HI electron bowtie analysis via Geant simulations of response functions [Boudouridis et al., 2020].

IV.2 Proton data contamination

IV.2.1 Contamination by relativistic electron

There are additional methods for identifying and removing contamination that are not included in this document; e.g., to estimate the level of radiation belt electron contamination in a proton channel with band energies >~5 MeV, consider the magnitude of diurnal variations (due to radiation belt electron fluxes) when the proton channel is at background level. (The primary source of SGPS backgrounds is GCR counts.)

IV.3 Saturation

“Count rate saturation occurs in some instruments leading to an artificial plateau in the observed count rate.”

NOAA handling of dead time.

- All channels are corrected for dead time
- Large dead time corrections are flagged

IV.4 Background

“Background levels due to thermal noise or other contamination such as cosmic rays are present in all particle instruments. These levels can be detected by examining data during intervals when the spacecraft are outside the trapping region for energetic electrons. For example, this occurs over the polar cap on open field lines for LANL-GPS and during extreme magnetospheric compression events for the geosynchronous region.”

MPS-HI intercalibrations of 1-12 MeV proton channels:

- Use periods of elevated solar proton fluxes
- Compare with SGPS fluxes in the same energy range

- Rely on periods of elevated (>10 nPa) solar wind dynamic pressure since SGPS and MPS-HI do not have the same look directions

No background subtraction of any kind is performed on MPS-HI 1-12 MeV proton channels based on these intercalibrations. Instead the reason for any discrepancies is sought.

"The background levels due to the GCR must be subtracted from the data."

GCR backgrounds are subtracted from MPS-HI electron channels E9-E11. Background subtraction is performed on a statistical basis over many months by modeling the MPS-HI and SGPS-X P11 cumulative distribution functions.

GCR backgrounds are not subtracted from SGPS channels.

- During a moderate SEP event, SGPS proton fluxes far exceed GCR background levels, typically by orders of magnitude.
- SGPS cross-comparisons are performed over the full range of observed fluxes, including background levels so that instrument responses can be compared in the transition to and at background levels, e.g., see Figure 1 showing that the GOES-16 SGPS-X P8C channel is reporting approximately a factor of 2 higher than GOES-13 EPS, and that the older EPS instrument has background levels ≈3.e-3 [#/cm^2-sr-s-MeV] higher than SGPS.
- Background subtraction would result in some negative flux values, obeying the statistics of the differences between two Poisson distributions (Skellam distribution).

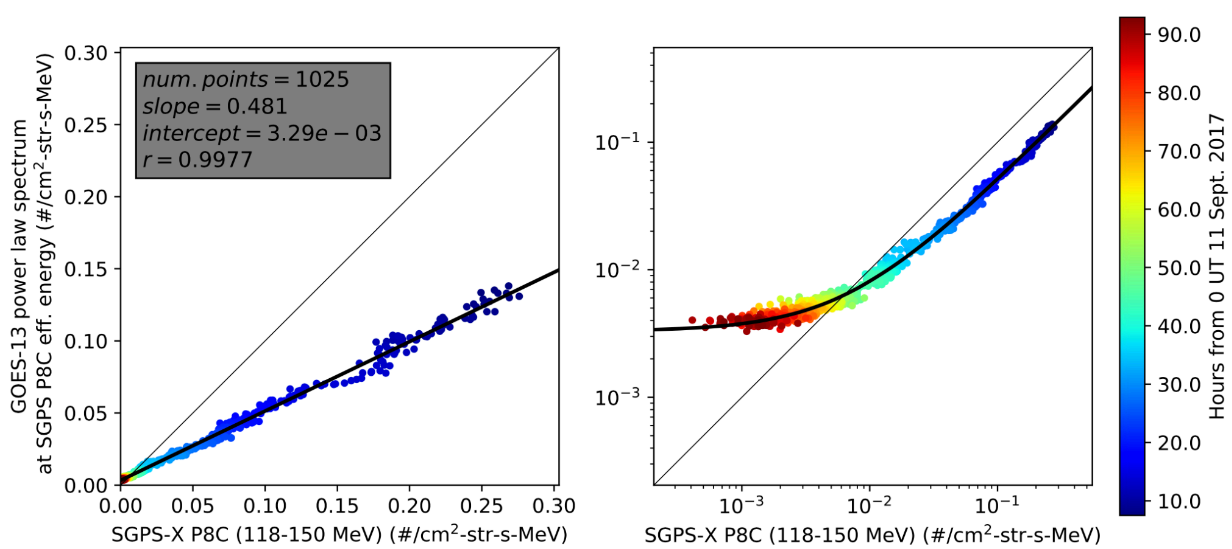

Figure 1. Geostationary Operational Environmental Satellites (GOES)-13 West versus Solar and Galactic Proton Sensor (SGPS)−X P8C scatter plots of simultaneous 5-min averages from 11 to 16 September

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].

"Because when count rates are very low the count rate itself is subject to instrument discretisation, so the background value can oscillate from one time to the next. So another safety factor must be used to exclude any data that is within a factor of three of the average background levels."

A data user may want to create longer time-averaged data to more accurately investigate variations near backgrounds or at low counts. A factor of 3 is arbitrary. Background removal may be performed by the data user if desired.

"Then for safety, three times the background level must be subtracted from the data and any resulting negative values need to be considered as "bad data"."

- Subtracting a factor of 3x background level will artificially bias the reported fluxes low. If backgrounds are high, it will significantly reduce the reported fluxes.
- If additional time averaging is performed by the data user (e.g., to reduce Poisson noise), then removal of negative values in the background subtracted fluxes will artificially bias the longer time-averages high.

IV.5 Signal to noise ratio

"At low flux values each individual horizontal line shows the discrete value available on the instrument… Times when such uncertainties are recorded must be removed."

- Poisson uncertainties are calculated, recorded and used to flag data. Data is not removed.
- The data user may wish to average the flux over a longer time interval to move the discretization to lower flux levels; e.g., if discretized flux values were removed from SGPS L1b (1s) data, then there would be almost no valid records in 1-hour averages, since we typically have 0 to a few counts in the 1s data samples. We expect the data user to identify and understand periods of low counts.

IV.6 Spacecraft charging bias

"...energy seen by the plasma instrument can be shifted because of the absolute potential of the spacecraft… To take this effect into account [and correct for it] the spacecraft potential must be known. This can be done by looking at the proton spectrum where the energy of the peak flux (protons are accelerated to the same energy) gives the value of the spacecraft absolute voltage."

Spacecraft frame charging produces an ion line in the data only when there is a sufficient population of low energy ambient ions. Presence of an ion line in MPS-LO ion data outside of eclipse periods is very uncommon.

IV.7 Other problems

"...some additional problem in the data may be found. It could be bad spacecraft location, glitches, spikes… An example is given in Figure 12 where some spikes on GOES data can be found. In this case an appropriate filter/editing must be defined."

How does one distinguish between spikes due to "glitches" and valid data?

V Obtaining coherent data

V.1 Inter-calibration based on trapped particle dynamics

"Inter-calibration will then consist of a simple scaling of all other instrument's spectra to a "gold standard". Inter-calibration is done using only omnidirectional fluxes, since not all instruments yield pitch-angle sorted fluxes and because use of such detailed data for this purpose would be a prohibitively huge task."

- It is not always known which measurement is more accurate.
- Several issues with comparing omnidirectional fluxes are noted further below

"on-orbit calibration procedure relies on having a "gold-standard" - a reference instrument that is trusted to perform the best and cleanest measurements possible. In the case of electrons, the MEA instrument on CRRES is chosen for energies between 300keV and 1.6 MeV…"

How does one compare current measurements to CRRES?

"In case of protons, the SEM instrument on GOES-08 is chosen for energies between 10 and 100 MeV. GOES proton data are now well known throughout the world and this database is more or less considered as a standard. Corrected differential channels are then used. As those measurements concern non trapped protons (except P1)…"

Note, the newer GOES-R series SGPSs have narrower energy bands and are likely more accurate in general than the older EPSs.

PRBEM Criteria: “the following list of conditions defining a “conjunction” are used:
1. L* < 6. and ΔL* < 0.1
2. Δ(B/Beq) < 0.1 and B/Beq as close as possible to one
3. Magnetic Local Time (MLT) within 2 hours of 06 :00 and 18 :00
4. Magnetospheric activity quiet (Kp < 2) for two days before conjunction
5. Δt < 3 hours
6. Particle energy > 100 keV (particle must be trapped)”

- The expected range of fluxes over an L*-B/Beq bin must be established to fully understand discrepancies in cross-comparisons.

- The contribution to discrepancies between measurements due to inaccuracies in the geomagnetic field model used to compute L* must be quantified.

- The PRBEM document says that “Inter-calibration is done using only omnidirectional fluxes,...”. At a given location in the magnetosphere, different pitch angles have different L* values (i.e., drift shell splitting). The omnidirectional flux at a given location in the magnetosphere corresponds to a range of L* values; e.g., when 6.0 RE, 0°N, 90°W is at 20h MLT, the equatorial pitch angle range 15°- 90° corresponds to an L* range 5.8-6.6.(1)

- Regarding the criteria “L* < 6.” and “MLT within 2 hours of 6:00 and 18:00 LT”: Along geostationary orbit within 2 hours of 6:00 and 18:00 LT, in quiet geomagnetic fields, L* does not go below L* ≈ 6.1 (with the minimum values ≈ 6.1 corresponding to 90° equatorial pitch angles at LTs 8:00 and 16:00). *The PRBEM criteria exclude inter-calibrations with and among GOES spacecraft.*(1)

- GOES-West and GOES-East longitudes are separated by 4h in local time so it is possible to meet criteria #3; However, since the geographic equatorial plane is inclined with respect to the geomagnetic equatorial plane, GOES-West is ≈5° above the magnetic equator and GOES-East is ≈10° above the magnetic equator. GOES-West and -East are at different magnetic L-values *and* view different portions of the pitch angle distribution. A consequence of this is that the daily averaged MPS-HI E11 (>2MeV) flux measured at GOES-West is on average a factor of about 2.5 higher than that measured at GOES-East [Meredith et al., 2015], and can be up to a factor of 5 different. GOES-West and GOES-East may have L*-J_2 conjunctions during geomagnetically disturbed periods, but geomagnetically disturbed periods violate criteria #4.

(1) L* results above obtained from the TS05 field model under quiet geomagnetic conditions (nominal solar wind, DST=0, and w-parameters set to 0).

V.2 Inter-calibration based on SEP

"L*>5.5 can be considered carefully – in this case the procedure is safe for E> 10 MeV"

- At geosynchronous, in quiet magnetospheric fields, there is geomagnetic shielding up to 40 – 80 MeV for protons arriving from eastward directions [Kress et al., 2021].
- Comparison of omnidirectional fluxes is not appropriate for SEPs at L ≈ 4-7 due to east-west anisotropy. Also, two SGPS look directions on each GOES spacecraft do not provide enough directional measurements to compute an omnidirectional flux.

"data are filtered such as only measurements done when L* is greater than 7 are kept."

- At the onset of a solar particle event, interplanetary SEP fluxes can be highly anisotropic. Occasionally this anisotropy can persist for many hours through the peak of the event.

References

Boudouridis, A., Rodriguez, J. V., Kress, B. T., Dichter, B. K., & Onsager, T. G. (2020). Development of a bowtie inversion technique for real‐time processing of the GOES‐16/‐17 SEISS MPS‐HI electron channels. Space Weather, 18, e2019SW002403. https://doi.org/10.1029/2019SW002403

Kress, B. T., Rodriguez, J. V., Boudouridis, A., Onsager, T. G., Dichter, B. K., Galica, G. E., & Tsui, S. (2021). Observations from NOAA's newest solar proton sensor. *Space Weather, 19*, e2021SW002750. https://doi. org/10.1029/2021SW002750

Meredith, N. P., R. B. Horne, J. D. Isles, and J. V. Rodriguez (2015), Extreme relativistic electron fluxes at geosynchronous orbit: Analysis of GOES E > 2 MeV electrons, Space Weather, 13, 170–184, doi:10.1002/2014SW001143.

Selesnick, R. S. and J. B. Blake, J. B. (2000). On the source location of radiation belt relativistic electrons. *Journal of Geophysical Research: Space Physics, 105*, A2, pp. 2607-2624.
