GSICS Space Weather Sub-Group
Propose method of near-real time and archival inter-calibration

Piers Jiggens, Hugh Evans

07/12/2023

Primary Reference Material

Main input is Panel on Radiation Belt Environment Modeling (PRBEM) - Data analysis procedure v1.2:

https://prbem.github.io/documents/Standard_Data_Analysis.pdf

This document notes that:

> *Here the term "inter-calibrated" means that **the response functions of all instruments must be well known** so that these data can be seamlessly merged. Ideally, given "perfect" instruments, no further efforts along these lines would be required. However energetic particles represent a challenging measurement task in space for many reasons. One critical reason is it is never possible to fly the amount of shielding required for a "clean" measurement, and a second is that it is impossible to recreate the full energetic particle environment the instrument will encounter in space in the lab for calibrations.*

It recommends the organisation of particle flux data by:

- E - Particle Energy
- α_{eq} – Equatorial pitch angle
- L^* - the Roederer L-parameter
- MLT – Magnetic Local Time

Magnetic Field Models

For the calculation of L^* internal and external magnetic field models are required

It is important to use the same(/similar – see IGRF time variation below) models for each data.

The PRBEM Data Analysis Procedure recommends:

- Internal Field Model - IGRF (decimal year + 0.5)
- External Field Model - Olson-Pfitzer quiet 1977 (see Note)

Two software libraries for calculating magnetic field coordinates are (both in FORTRAN)

- IRBEM: https://github.com/PRBEM/IRBEM
- UNILIB: https://essr.esa.int/project/unilib-magnetic-field-library

Note: the external field models can also include dynamics for the conditions, e.g. high Kp, Dst, etc. This can have an impact when determining conjunctions during active periods. The O-P Quiet does not include such variability but does include variations for the tail, etc.

“Sanitising” data: Contamination of Electron Channels

esa

Electrons

- Removal of data contaminated by protons is necessary
  - Compare to SEP data from L*>7 or at GEO and remove correlated fluxes from analysis
  - Correlate to on-board proton channels and remove points well correlated to one or more proton channels
- Possible consideration of Bremsstrahlung from relativistic electrons
- Removal of "spikes" and spurious data points
- Classification of data into quality levels – how much can the data be trusted to be correct.

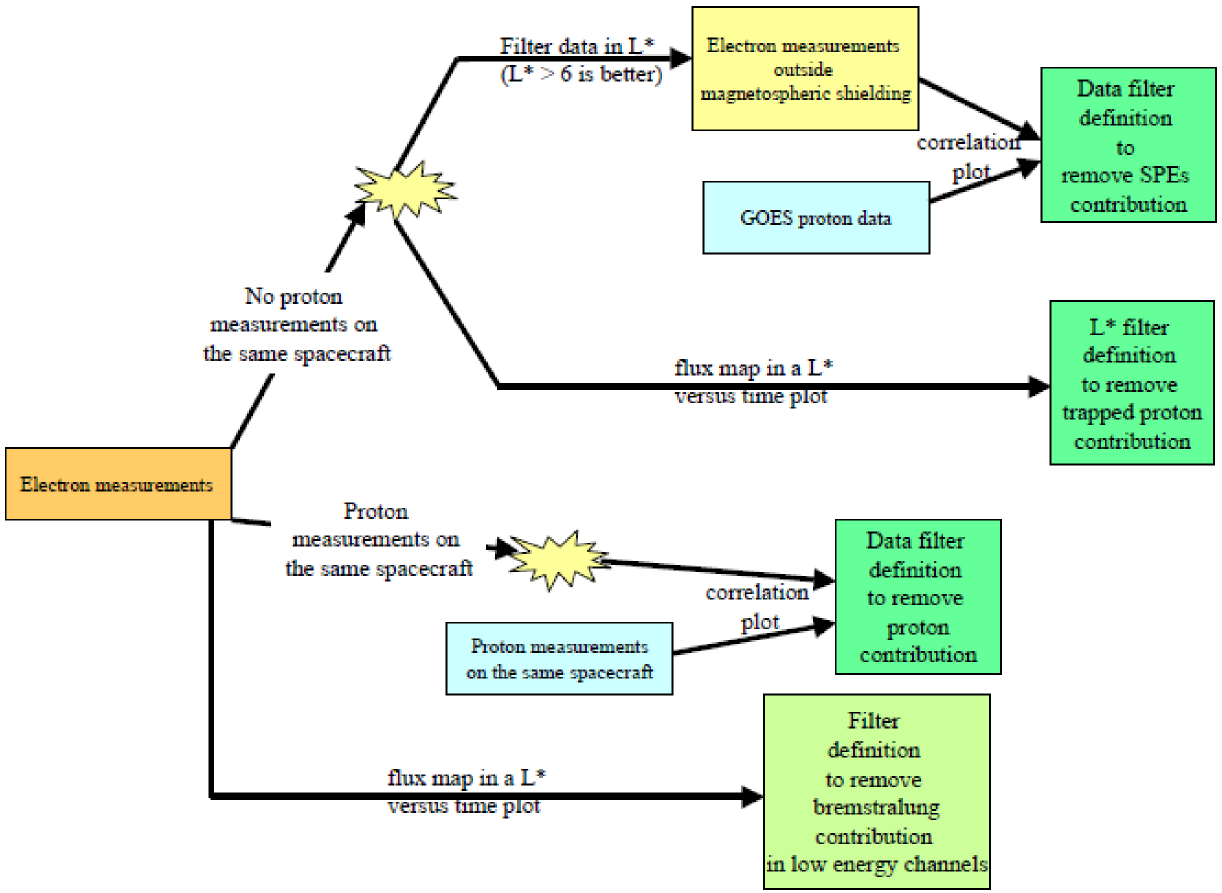

Figure 4: Logic to define data filter to remove any contamination in trapped electron measurements.

“Sanitising” data: Contamination of Proton Channels

Protons

- Removal of data contaminated by high-energy electrons
  - Should be present outside proton trapping region and not at a time of SEP events
  - May be a problem in the inner belt
- Removal of high energy proton contamination from low energy channels.
- Possible consideration of Bremsstrahlung from energetic electrons.
- Removal of "spikes" and spurious data points
- Classification of data into quality levels – how much can the data be trusted to be correct.

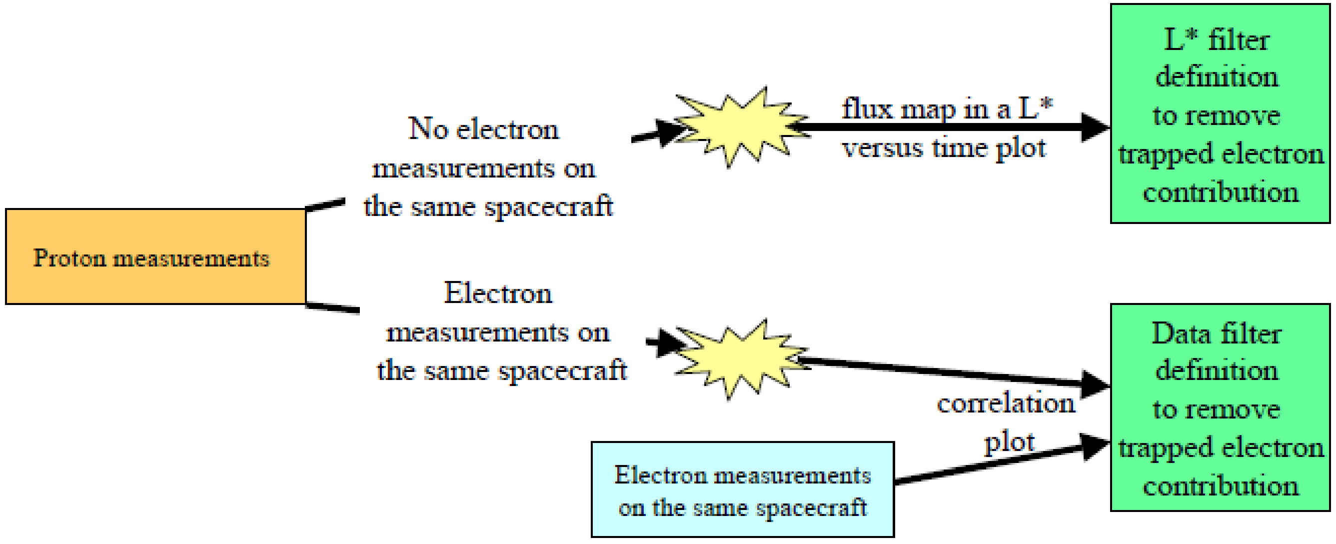

Figure 7: Logic to define data filter to remove any contamination in trapped proton measurements

“Sanitising” data: Saturation and Background

Saturation

- Less common now but especially with older instruments not developed as monitors one has to be careful with saturation
    - Can appear as a plateau in the data approaching a maximum flux level
    - Can appear as drops and rises
- Related effects such as deadtime and pile-up may need to be considered

Background

- Two main sources of background are:
    - Galactic Cosmic Rays (GCRs) – because they can get almost everywhere
    - Instrument Noise
- Levels should be calculated (time varying especially for GCR) and subtracted, but care must be taken, this can lead to negative fluxes.

Signal-to-Noise

- If after background subtraction, we are in a region of Poisson noise (i.e. fixed levels of flux determined by integer counts) that data should be ignored due to high intrinsic uncertainty on fluxes

“Sanitising” data: Other

Spacecraft Charging

For low energies the spacecraft potential needs to be considered

Measurements made below the absolute voltage of the spacecraft should be ignored

Other energies should be shifted to compensate

Glitches/Spikes

Can be an issue in the transmission of data or corruption on-board.

Care must be given for saturation and pile-up

Instrumentation "features"

Response sensitive to Temperature (amplifier gain, RadFETs, etc)

Instrument Aging – drifts in comparators, amplifiers, etc.

Instrument specific effects

Gold Standard Datasets

These datasets are typically considered to be from "Science Class" instrumentation, where the instruments are (usually) the primary instrumentation on a purpose-built mission, e.g.:

- Radiation Belt Storm Probes (RBSP - "Van Allen Probes")
- Combined Release and Radiation Effects Satellite (CRRES)
- Energetic Particle Telescope (PROBA-V/EPT)
- SEPEM Reference Dataset (based on IMP-8 with GOES x-cal)
- Others…? (e.g. ARASE)

These datasets should be of high quality, low background, contamination, and be exceptionally well characterised and calibrated.

Such datasets are used to cross calibrate "monitor class" datasets.

Conjunctions for Cross Calibration

The objective is to find times/positions where the environments measured by the instruments are the same, or at least as nearly the same as to be practicable.

Magnetospheric

Conjunctions must be determined considering:

- Time
- Magnetospheric location (L^*, α_{Eq}, MLT, etc)
    - MLT dependence can be reduced during active times
- Pitch angle of instrument & Environment Anisotropy
- Magnetospheric quiet conditions: Kp < 4 (?) for *X* days.
    - Some cases (e.g. high-energy, > 2 MeV, electrons) require this to be relaxed for good SNR
- Consistent Instrument energy channels

During SPEs

Conjunctions must be determined considering:

- Time (consistent phasing of the event)
- Geomagnetic shielding of spacecraft (L>7 for mid/high energy protons)
- During a sufficiently large solar particle event
- Anisotropy of the event:
    - rising phase may be anisotropic
    - Geomagnetic shielding can impact isotropy
- For interplanetary missions: consistent solar connection.

Conclusions/Recommendations

Conclusions

- Stick to COSPAR PRBEM to the greatest extent possible
- The GSICS group should adopt these and tailor cross-calibration schemes
- Follow PRBEM standards for particle fluxes and count rates as well
- Plus investigate the response function file format standards
    - And encourage everyone to publish their response functions
- Levels of data are a bit different in different places/projects

Recommendations

- Possible expansion of standard datasets
- Cross-calibration at quiet times
- Validation at more active times
- Impact of different X-calibration pipelines
    - Issue of lack of modern SPEs
- Relax delta-t to match MLT in GEO
    - Or perform daily averages
- Consider use of (cross-calibrated) proxy datasets which do make conjunctions without relaxation of delta-t
    - ARASE actually allows us to make LEO-GTO-GEO cross-calibrations in one step with high-quality data
- Standardise data Levels for this group