Using the SPENVIS SEE Tools

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Introduction

- The SPENVIS SEE tools:
  - LETORB: calculates LET and proton spectrum
  - UPSETO: calculates SEE upset rates from LET & p^+ spectrum
- These require as inputs:
  - Orbit
  - Trapped protons (optional)
  - Future implementation: more complex solar proton spectra (flux, fluence, PSYCHIC, etc)
  - Device parameters (from test data, etc.)

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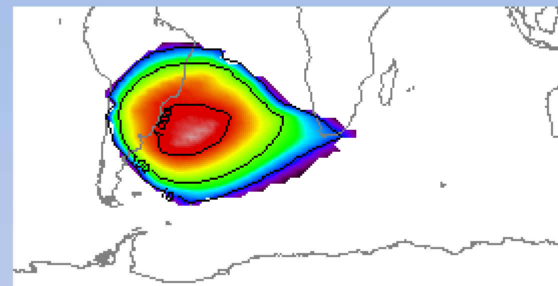
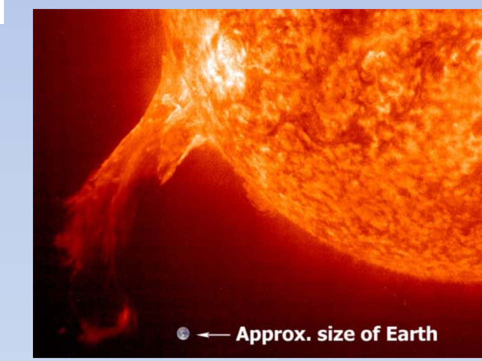
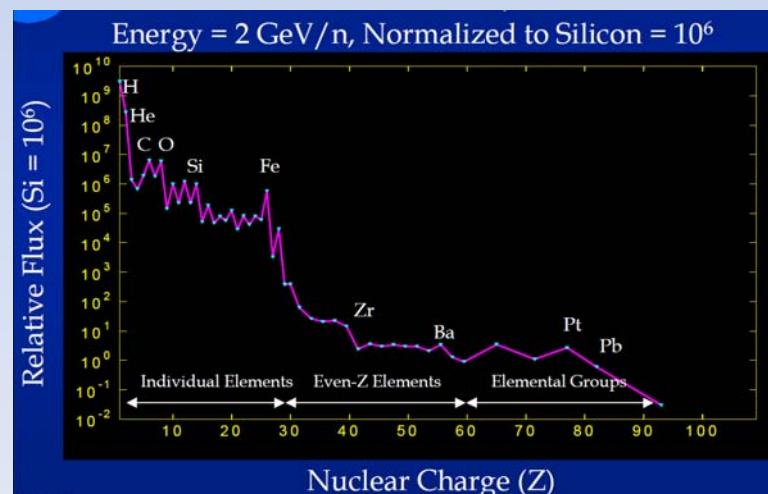
- Required outputs:
  - Total mission SEE rates: used in s/c design for part selection and data correction. Applicable to all subsystems on the s/c.
    - Non-destructive: rate specified by design (EDAC, etc.)
    - Destructive: 1/rate >> operational time.
  - Worst case SEE rates: used in s/c design for part selection and mitigation. Applicable to critical subsystems on the s/c.
    - Non-destructive: used to specify operational constraints
    - Destructive: risk of event accepted by project.
  - Global SEE rates for operational uses for risk mitigation.

Environment Sources



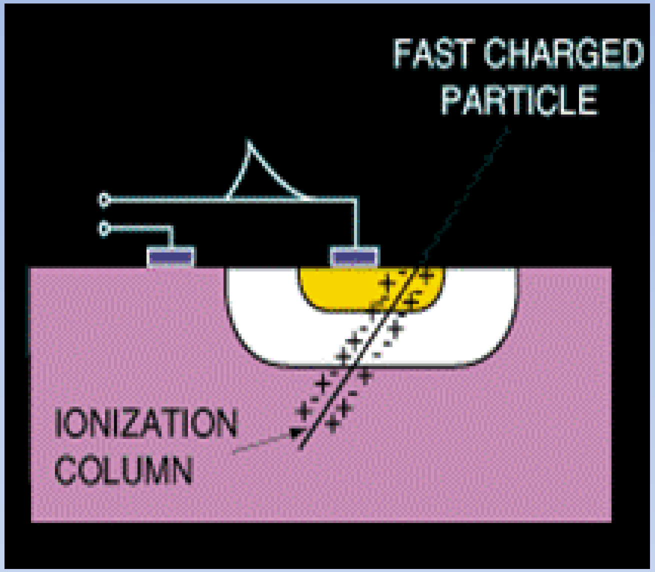


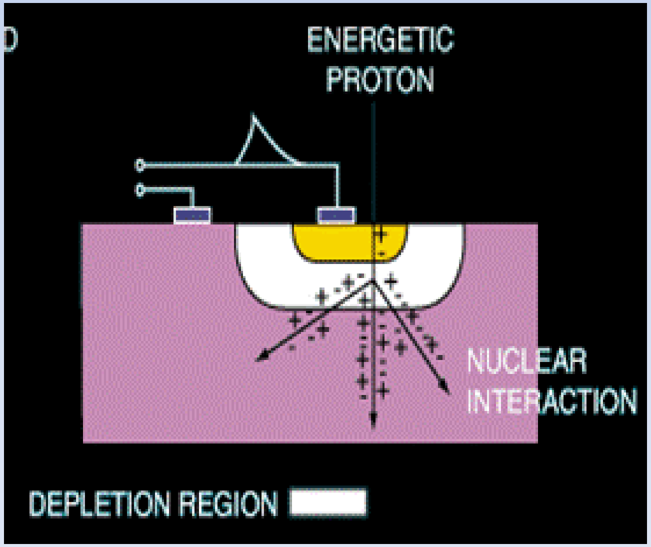
- Sun Synchronous Orbit
  - Trapped Protons
    - AP8MAX
    - AP8MIN
  - Solar Protons
    - Included in LETORB (CREME-86/M8)
    - Future: CREME-96 worst case models.
    - Future: will be derived from Solar Proton models as well (ESP/PSYCHIC)
    - Geomagnetic shielding
  - Cosmic Rays
    - CREME-86 models (M=3, M=1)
    - ISO-15390 model (ECSS-E-ST-10-04C standard)
    - Geomagnetic shielding
- Shielding:
  - Generally assume 1 g/cm^2 of spherical shielding.
  - SEE calculations are generally stable with shielding (penetrating particles) over s/c shielding range.



Upset Calculation - Theory

- Ions: cause upsets via ionization; this depends on the length of the ionization column in the sensitive volume of the component.
- Protons: cause upsets via a nuclear interaction leading to an ionization column.

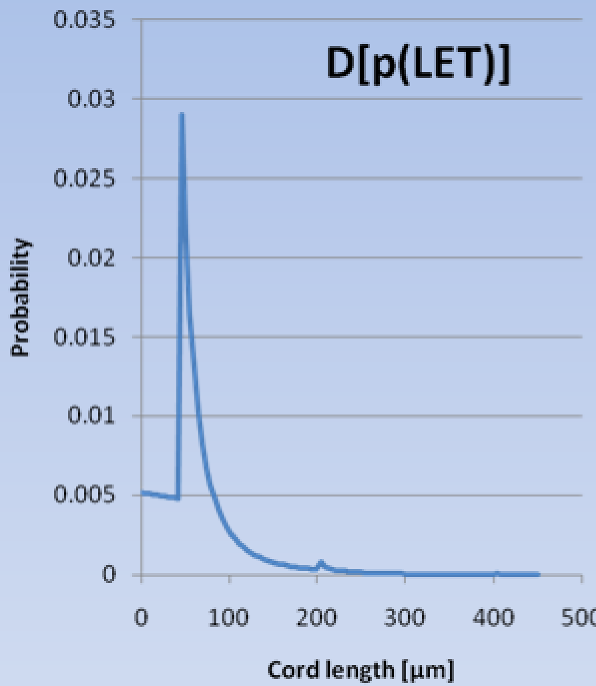




Upset Calculation - Ions

- CREME 86/96 RPP method:
  - Device Dimensions (l×w×h) → RPP path length distribution. These dimensions are derived from actual device dimension measurements, the cross section test data and device thickness.
  - Critical Charge (Q_c) – proportional to LET_{th}.
  - Cross section: is from the device test data.

  In this analysis, the critical charge was derived from a parametric study of on-orbit experience (MTBF).



$$SEUrate(\#/bit - s) = 22.5\pi\sigma Q_{crit} \int_{22.5Q_{cri}/p_{max}}^{LET_{max}} \frac{D[p(LET)]f(LET)}{LET^2} dLET$$

N.B.: 22.5 is for Silicon, for GaAs this becomes 30.0

Upset Calculation - Theory

- Protons: CREME 86/96 method:

  Cross-section data (Bendel, Weibull, Profit)

  In principle, there are no angular effects to consider.

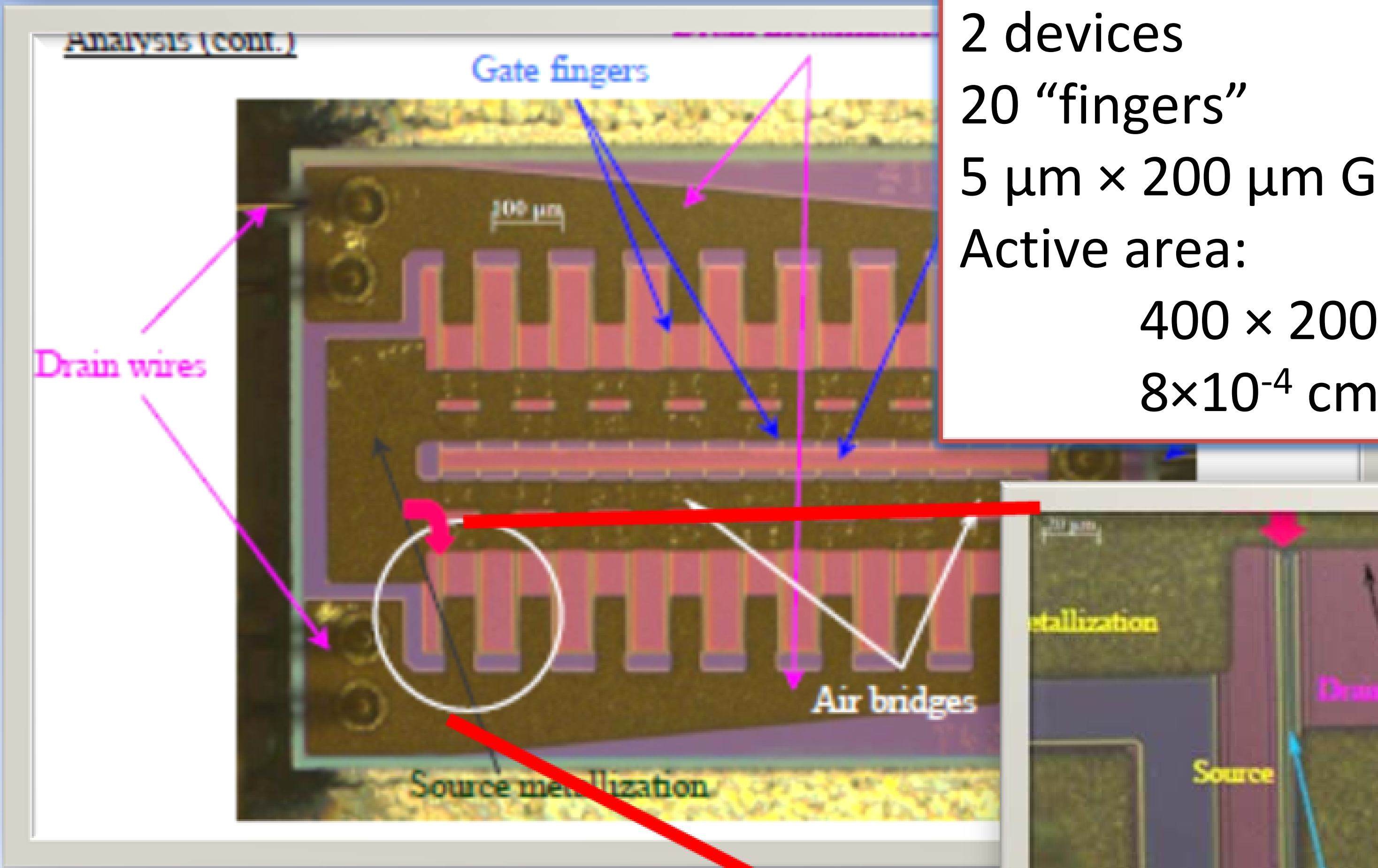
$$SEErate = \int f(E)\sigma(E)dE$$

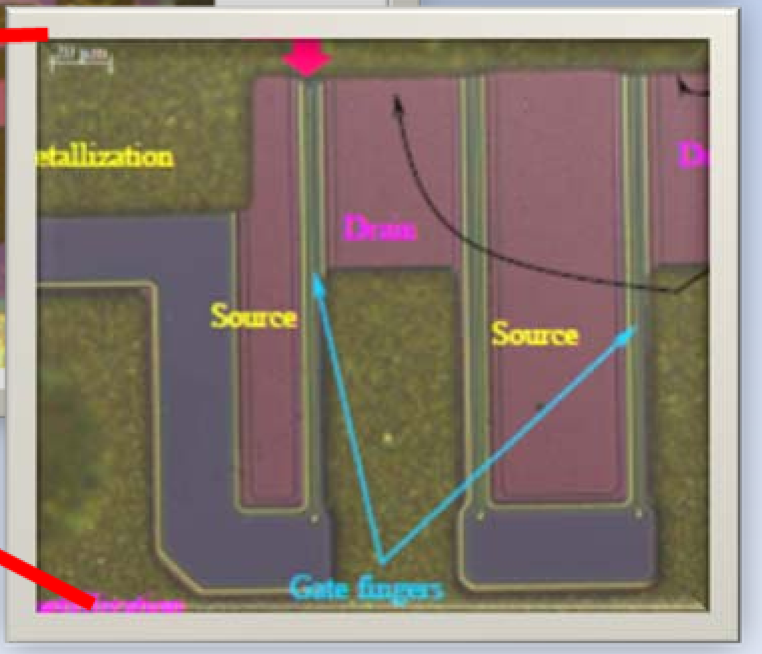
The Analysis

- Calculate the LET and proton spectra (LETORB)
- Determine device characteristics
- Calculate upset rates from trapped protons, solar particles and GCRs (UPSET)

Device Dimensions

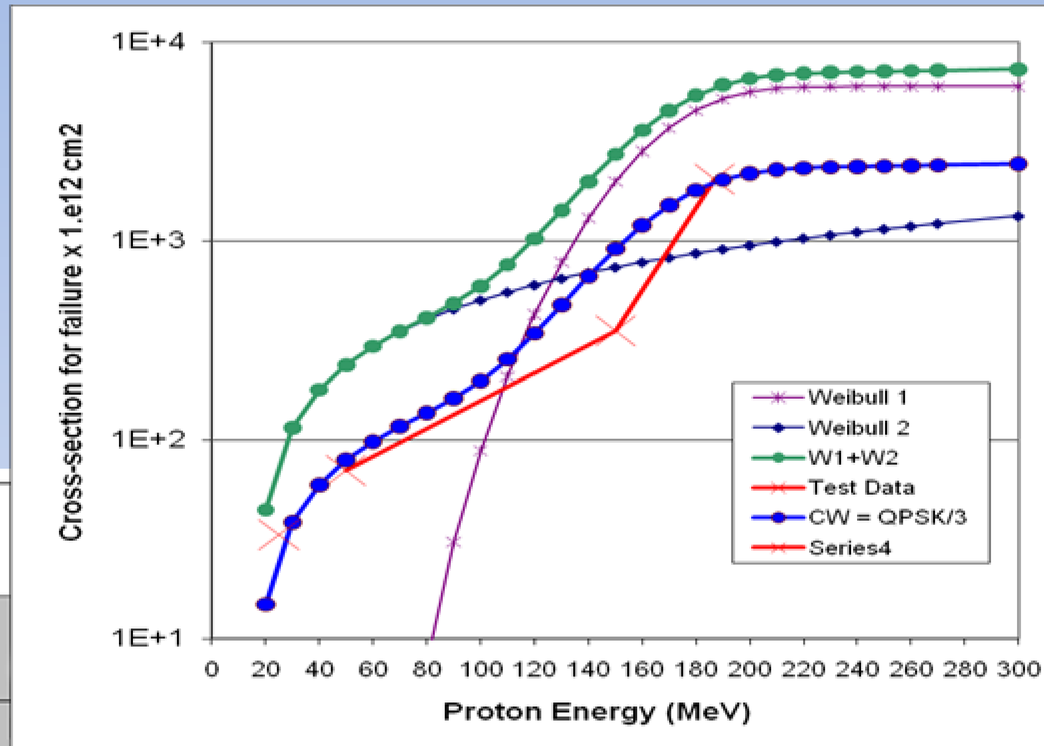
2 devices
20 “fingers”
5 µm × 200 µm Gates
Active area:
$400 \times 200\ \mu m^2 =$
$8\times10^{-4}\ cm^2$



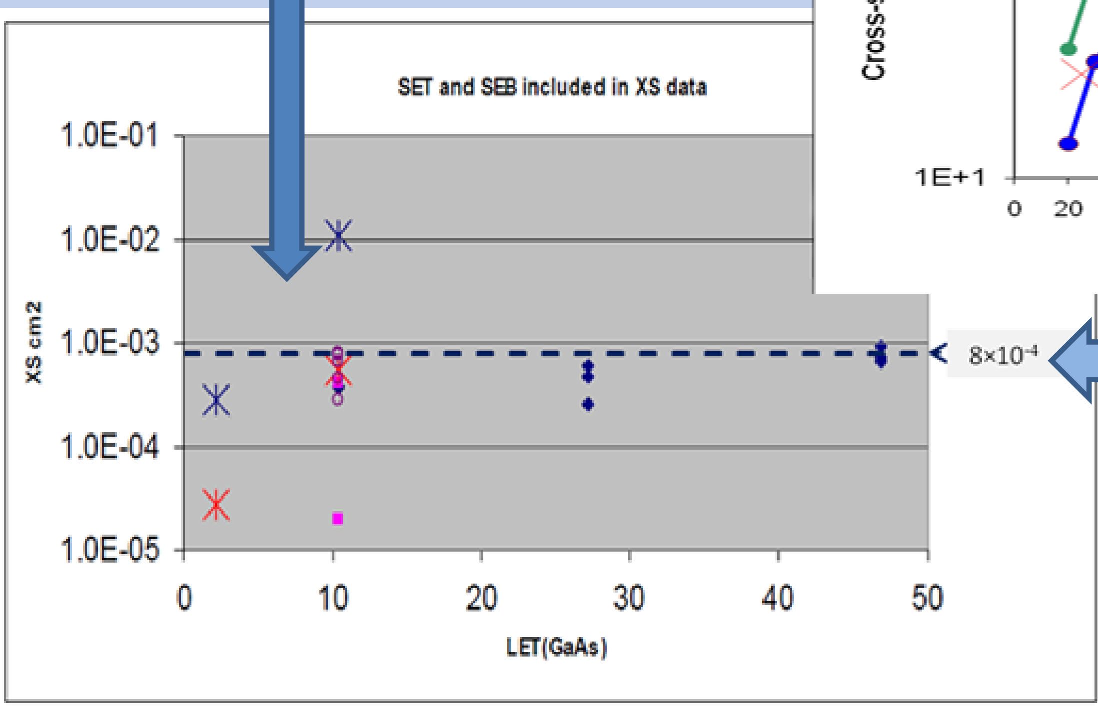


Device Test Data

Proton test data



No obvious LET_{th}

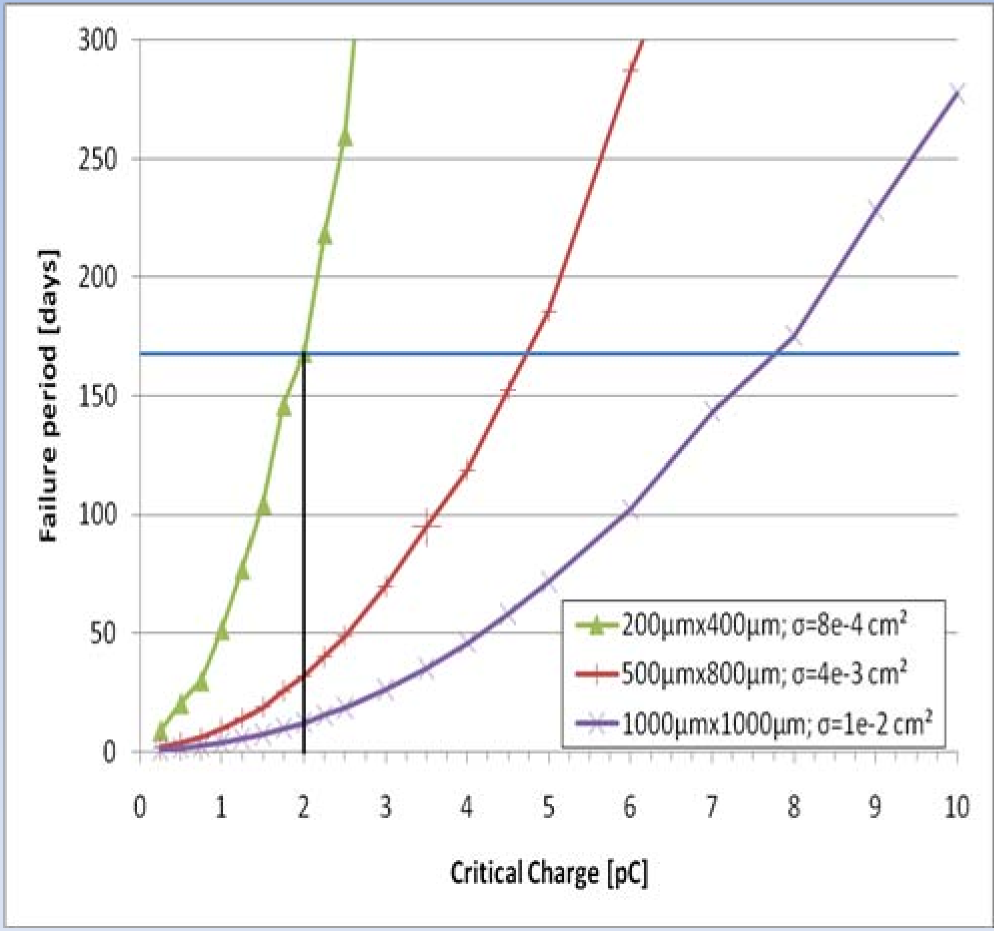


Test saturation cross section matches the visual inspection

Heavy Ion test data

UPSET device parameters

- Ion Rates:
  - Device dimensions calculated from visual inspection and cross section of test data (<u>42µm × 400 µm × 200 µm</u>).
  - Critical charge (<u>2 pC</u>) was derived from a parametric analysis based on the on-orbit experience; poor definition of the LET_{th} provides values from 2 – 10 MeV cm²/mg
- Proton Rates:
  - It was decided that a double Weibull fit was the best form for the proton data – to capture the Knee.



SPENVIS LET Calculation

Radiation sources and effects: Ion energy and LET spectra model parameters - Mozilla Firefox

http://www.spenvis.oma.be/htbin/spenvis.exe/SSO?%23resetToPrevious(letorb_par.html)

UP

SPENVIS Project: SSO

Radiation sources and effects

Ion energy and LET spectra: Input parameters

Output

Help

Target material:	GaAs (SRIM2008)
Shielding thickness (Al equivalent):	1 g/cm2
Ion range:	H to Ni
Galactic cosmic rays model:	ISO-15390 standard model

Model developed by

Lomonosov Moscow State University

Skobeltsyn Institute of Nuclear Physics

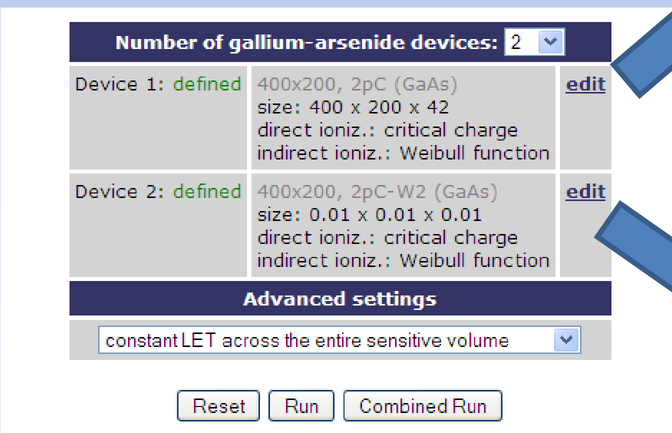
Solar activity data:	Solar Minimum (May 1996)
Geomagnetic shielding:	apply for quiet magnetosphere
Trapped protons:	taken into account
Output resolution:	spectra for each orbital point

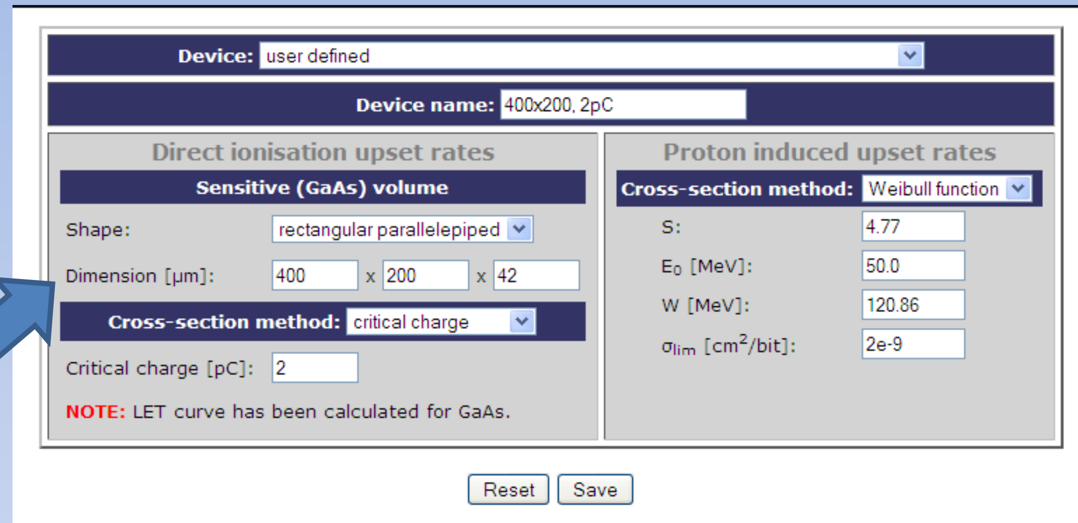
Reset Run Combined Run

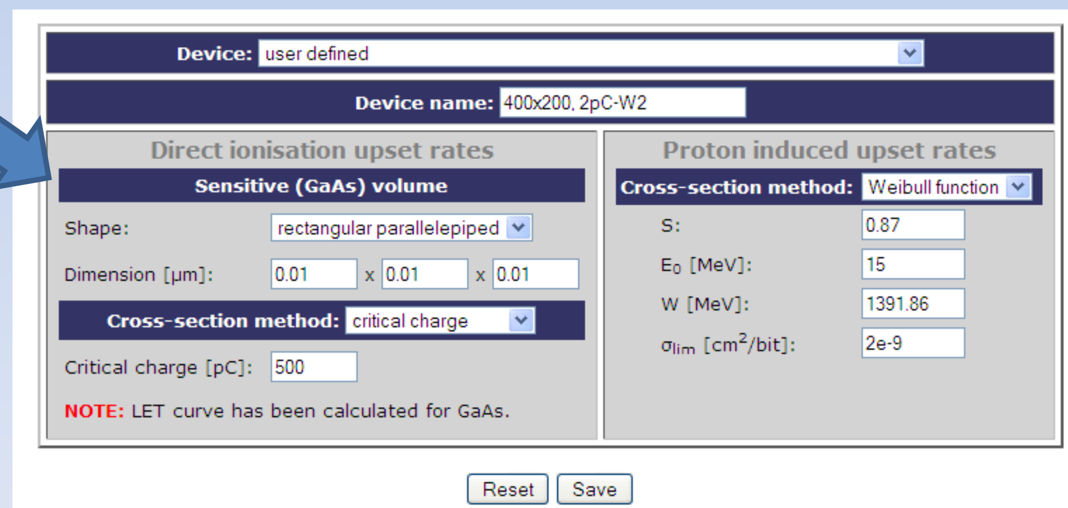
Done

SPENVIS Upset Calc.

To process the double Weibull fit for the proton upsets, we used two devices, one for each fit and then added the results.

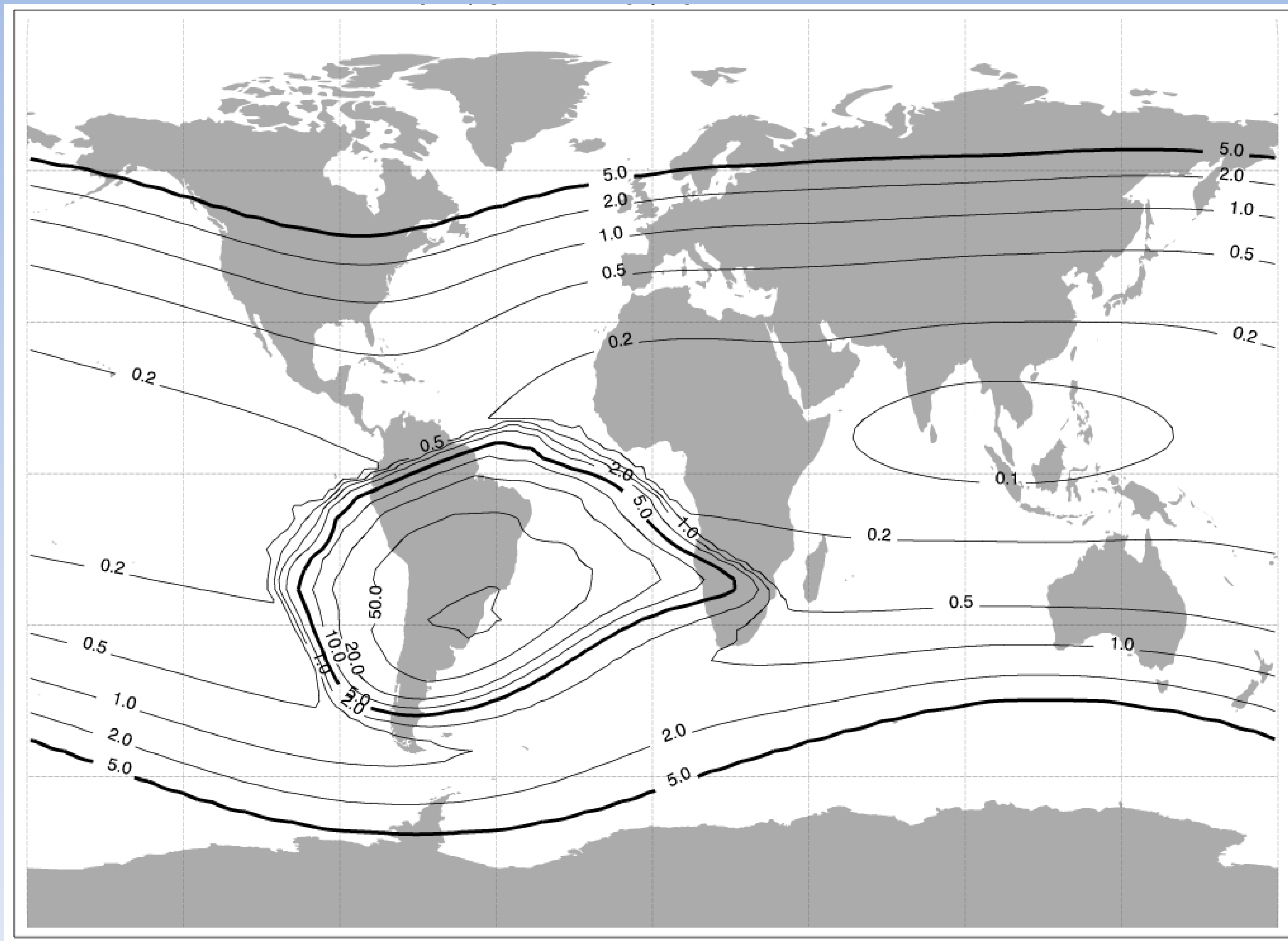






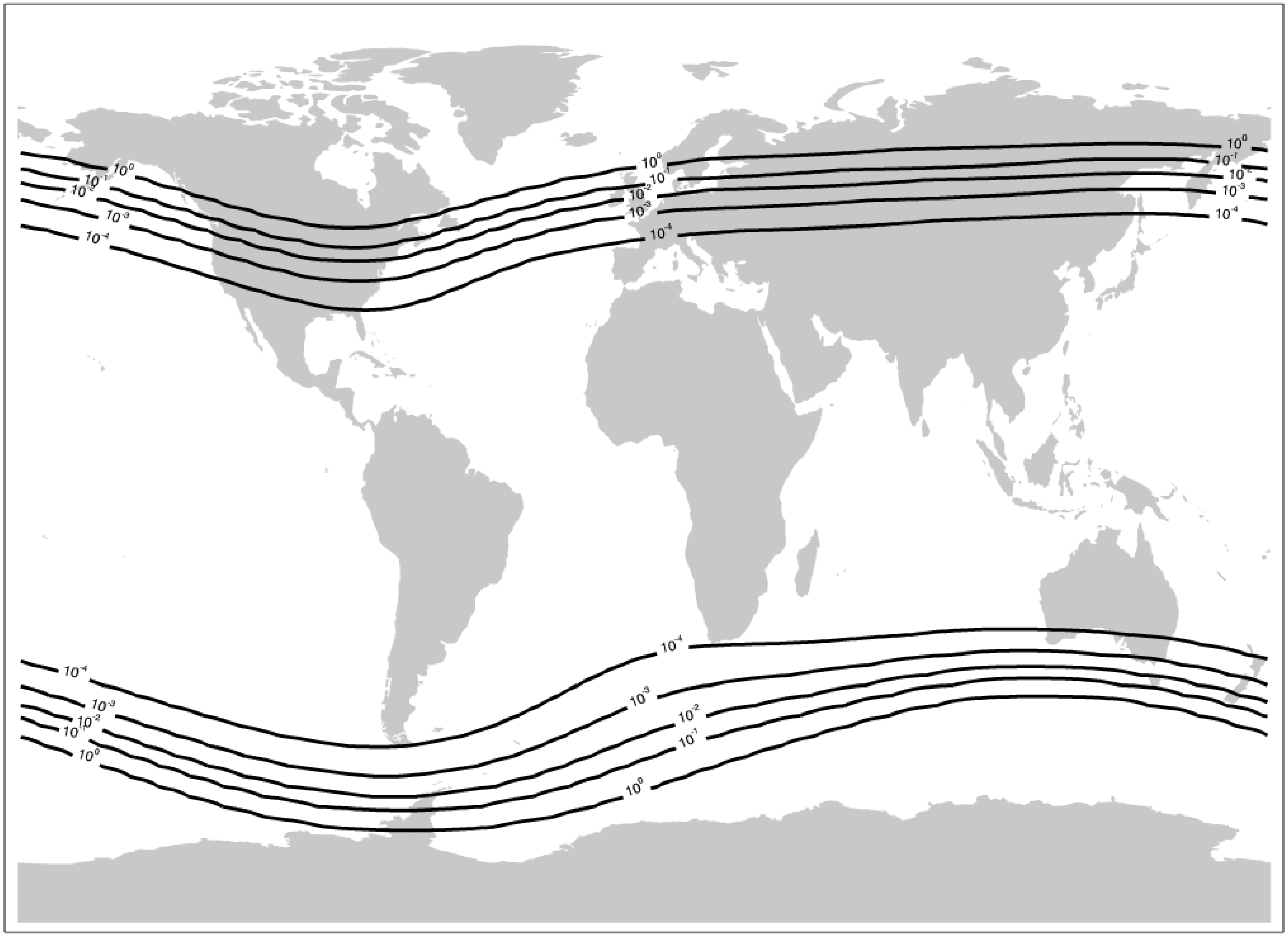
Post Processed results.

GCR and Trapped proton rates – Nominal case



Post Processed results.

Solar Energetic Particle rates – worst 5 minute case



Validation Analysis

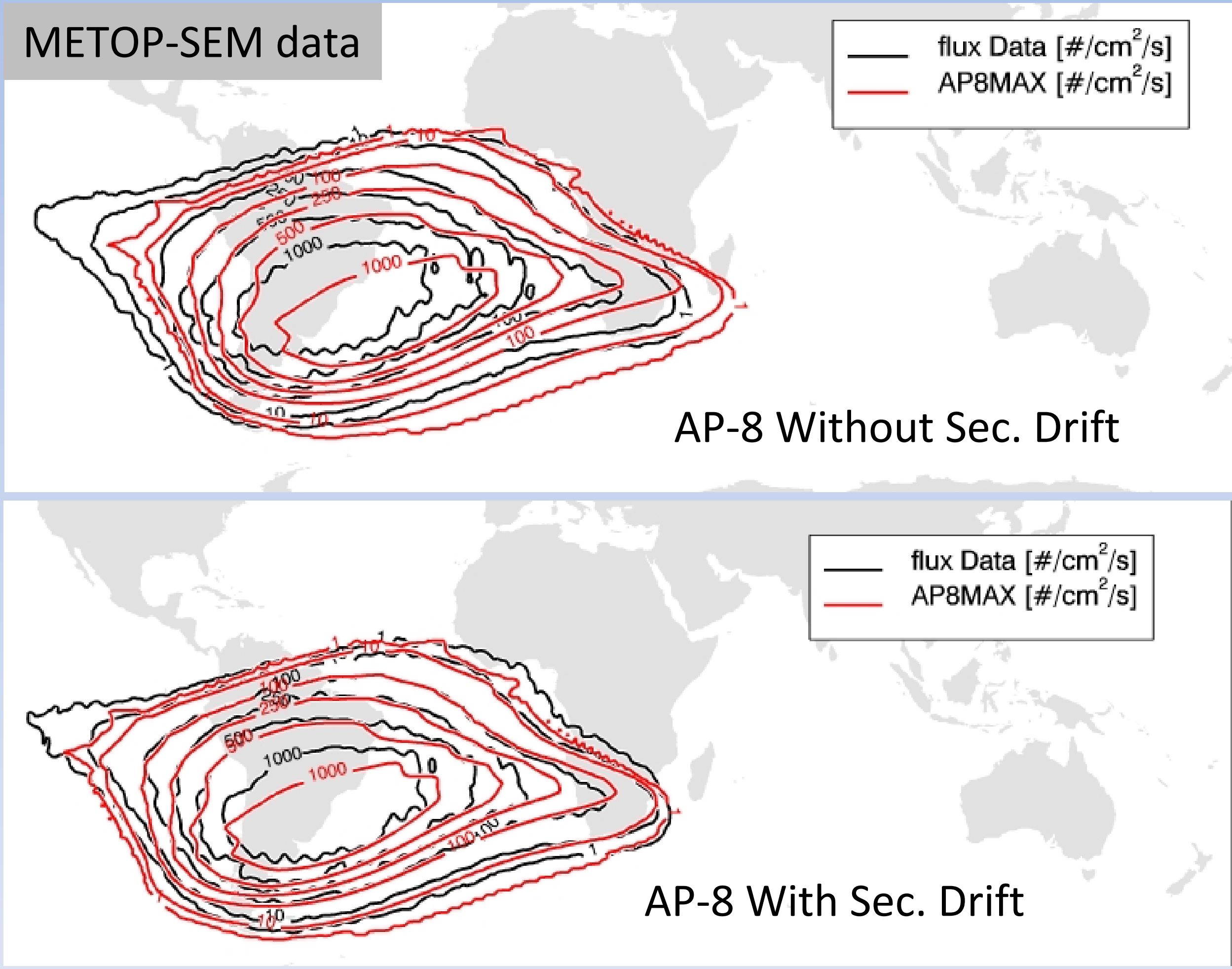
- Trapped protons:
  - Which model is more appropriate: AP-8 MIN or MAX?
  - Secular drift of the SAA
- Geomagnetic shielding

Validation: Trapped p^+

Secular drift:

south Atlantic Anomaly has shifted West since AP-8 was created (1965).

TREND study showed a 0.3° Westward drift.

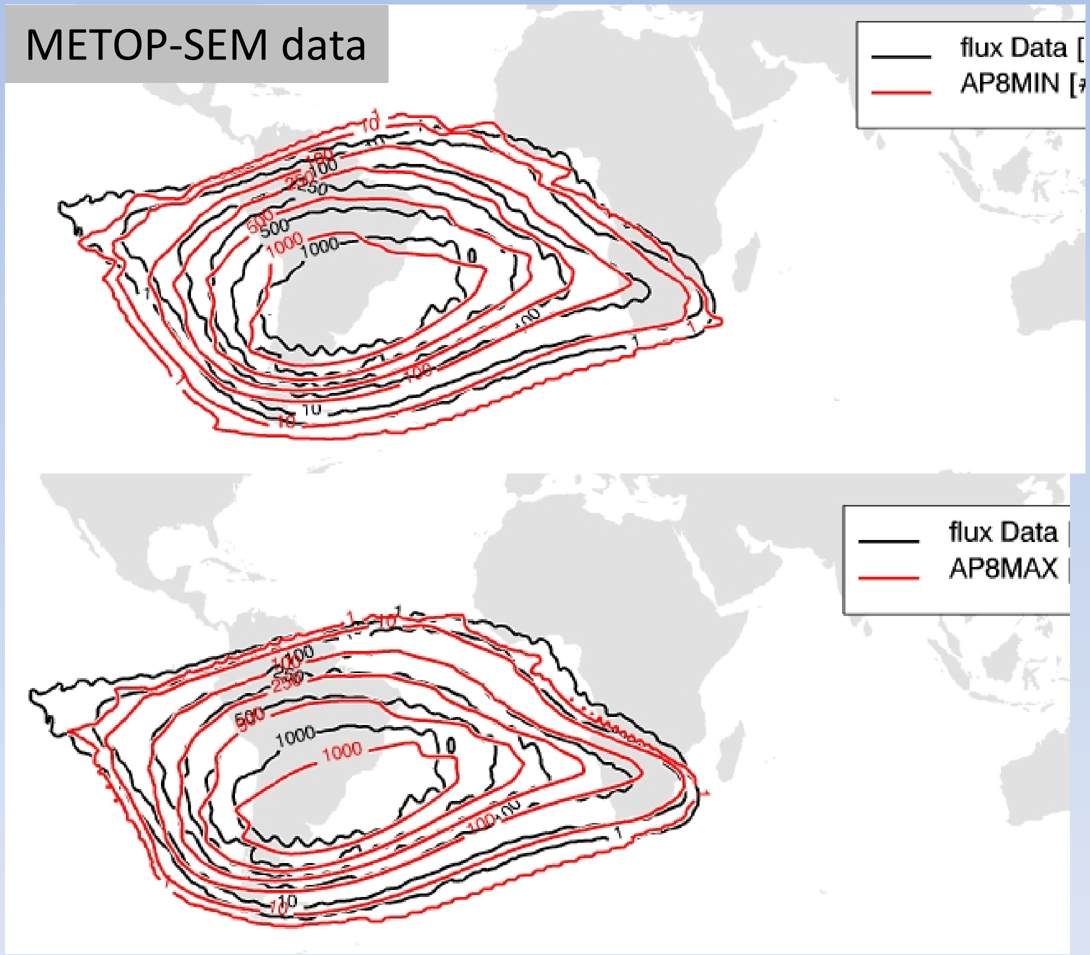


N.B. Energy range is 70 → 140 MeV, the critical range for this component.

Validation: Trapped p^+

Does the magnitude of the AP-8 models fit the data?

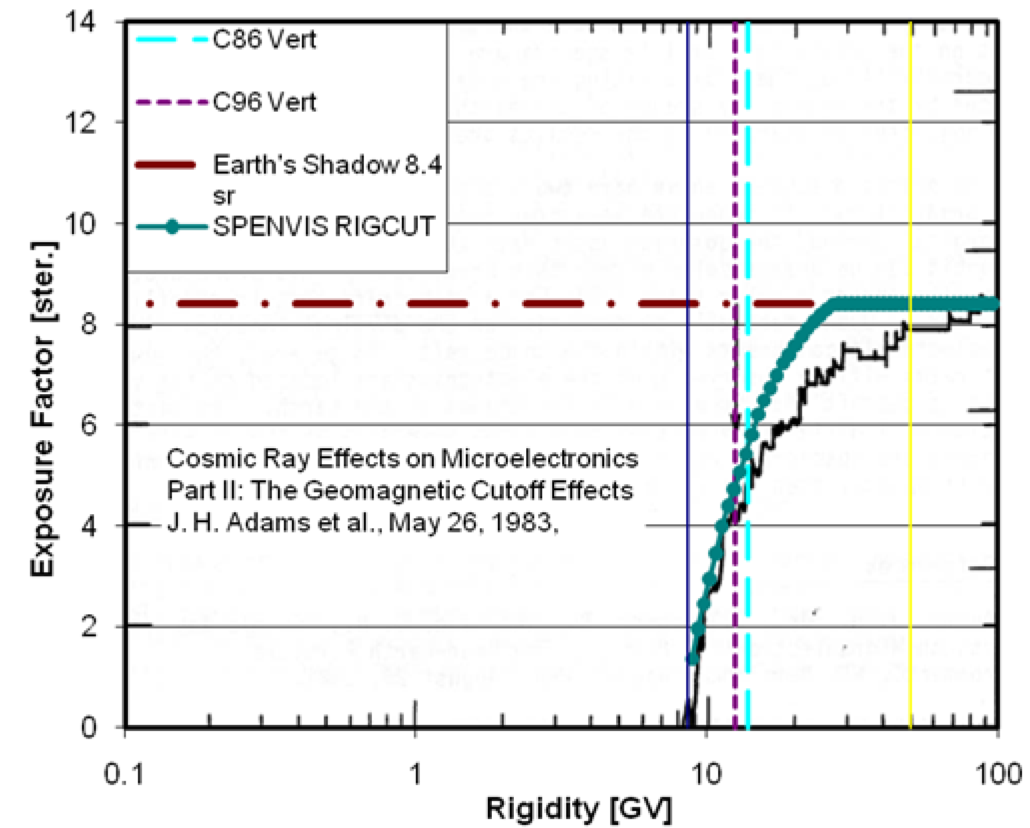
- Contours of MAX match better than MIN, but peak values in the centre are better matched by MIN
- Geographic extent of MAX agrees with METOP SEM data.



N.B. Energy range is 70 → 140 MeV, the critical range for this component.

Validation: Geo Shielding

- SPENVIS provides an average over the look direction.
- CREME96 uses a simplified form for vertical arrival.

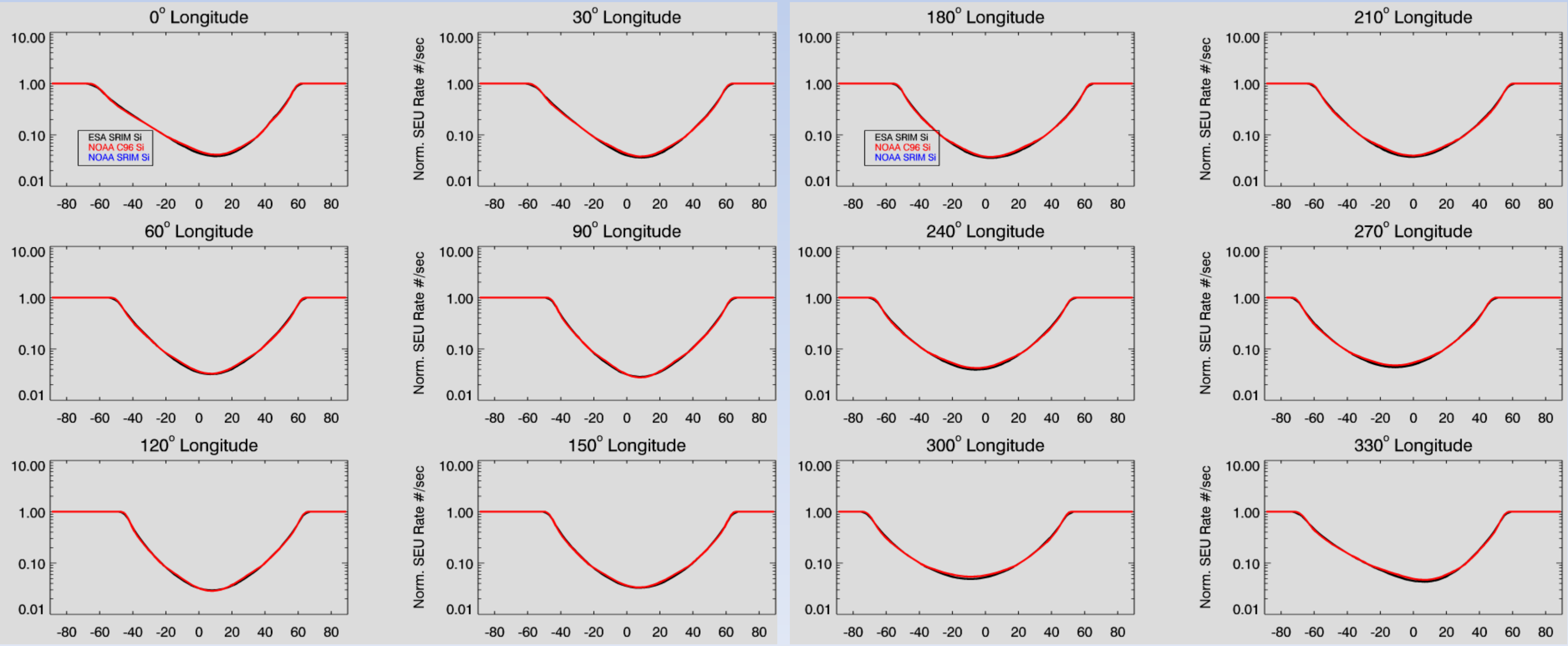


The precise geomagnetic cutoff transmission function, averaged over all arrival directions, for a point at 20° Latitude, 0° Longitude, and 400 km altitude. The exposure factor is the solid angle through which cosmic rays may arrive at this

$$SPENVIS : P_c = \frac{M \cos^4 \lambda}{R^2 \left[1 + \sqrt{1 - \cos \zeta \cos^3 \lambda}\right]^2}$$ Vs. $$CREME\,96 : P_c = \frac{14.5}{L^2}$$

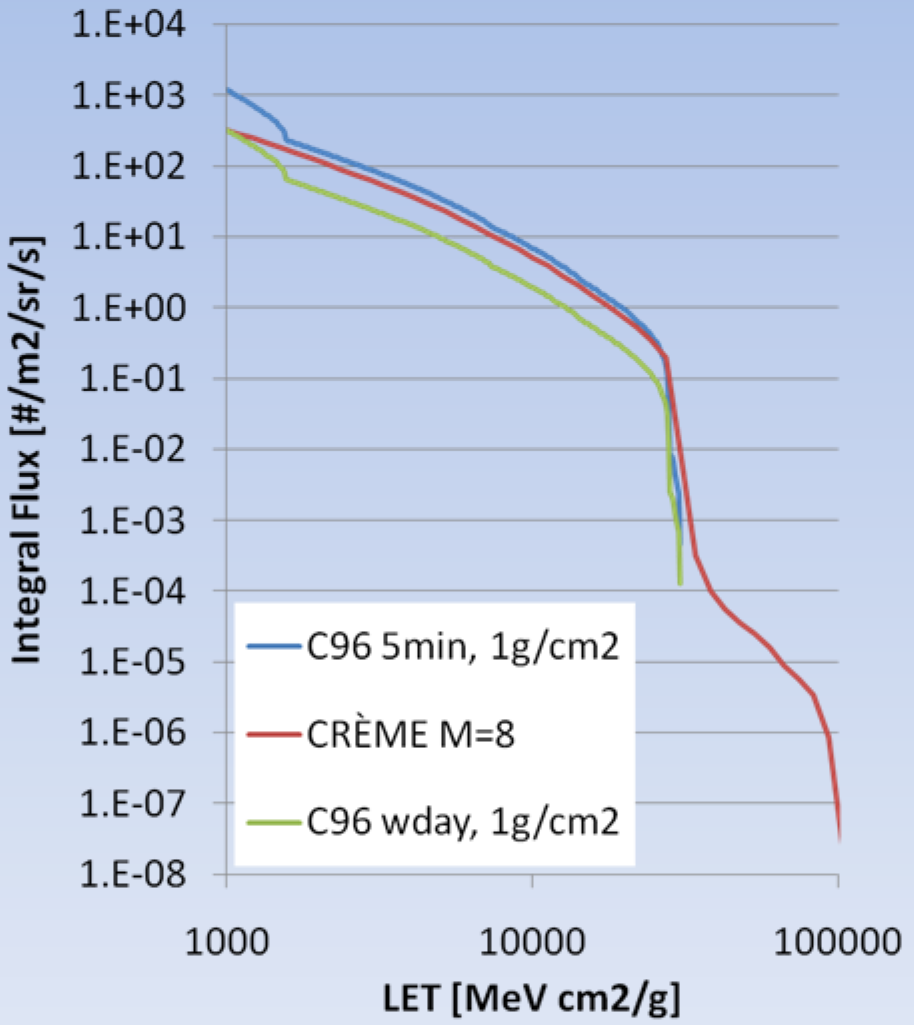
Validation of Geomagnetic Shielding – CREME96

- The IGRF field model was added to the SPENVIS LETORB model, for comparison with CREME-96 and to provide more geographically representative shielding.



Solar Energetic Particles

- Added CREME-96 ion spectra to LETORB:
  - Worst 5-minute
  - Worst day
  - Worst week
- These are the ECSS-E-ST-10-04C required models.



Conclusions

- Upset rates for both Heavy ions, trapped protons and solar particles calculated and geographic maps created for operational risk mitigation.
- AP-8 MAX showed better agreement with data in the required energy range and phase of the solar cycle than MIN.
- Implemented IGRF model for Geomagnetic shielding and validated against CREME-96.
- Implemented CREME-96 worst case solar particle spectra.

- NOTE: the next generation of methods to calculate SEE will become very complex (Monte-Carlo analyses, etc.) and will require a similarly complex user interface – this will be a challenge for the web engineer.