New Operational Algorithms for Charged Particle Data from Low-Altitude Polar-Orbiting Satellites

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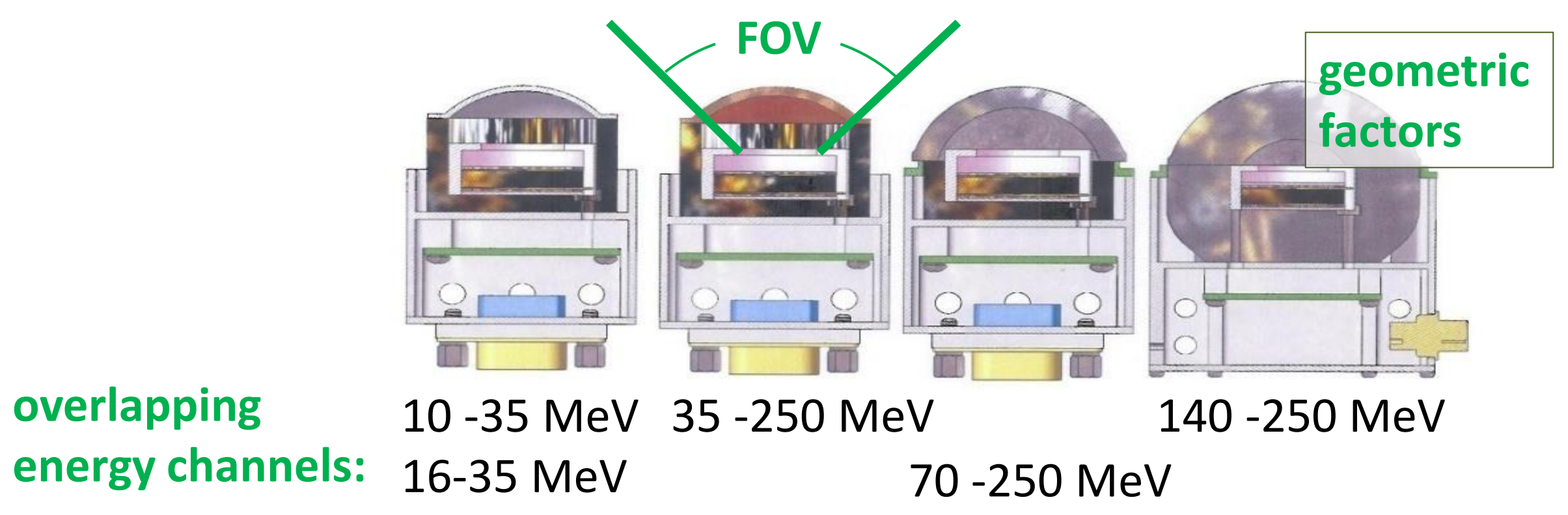
Summary

NOAA is developing operational algorithms for the next generation of low-altitude polar-orbiting weather satellites. Here we focus on two new algorithms for charged particles: **Energetic Ions** and **Auroral Energy Deposition**. Both algorithms take advantage of the planned improved performance of the Space Environment Monitor – Next (SEM-N) sensors over the earlier SEM instruments flown on the NOAA Polar Orbiting Environmental Satellites (POES). These new instruments are planned to fly on the Defense Weather Satellite System (DWSS), the successor to the Defense Meteorological Satellite Program (DMSP).

Energetic Ions Algorithm

This algorithm derives a differential energy flux spectrum for protons with energies from 10-250 MeV from particle counts by iterating a piecewise power law fit. The algorithm provides the data in energy flux units (MeV cm^2 s^{-1} sr^{-1} MeV^{-1}) instead of just count rates as was done in the past, making the data generally more useful and easier to integrate into higher level products.

High Energy Omnidirectional Detectors

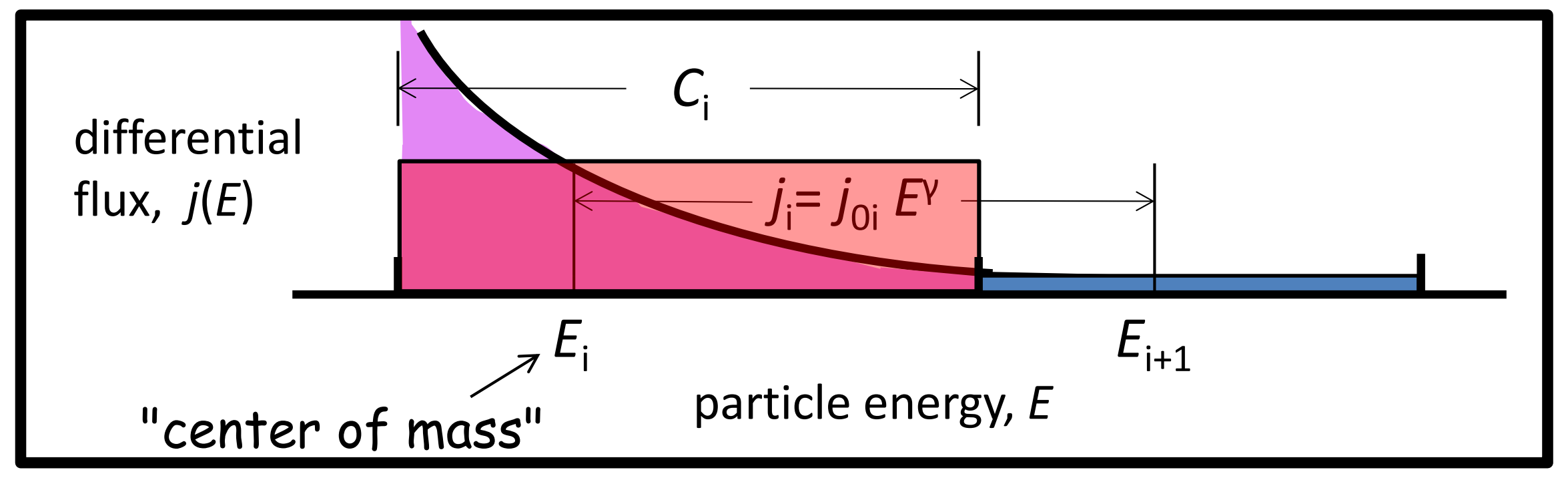


The algorithm input is count rates from the four SEM-N high energy detectors. The algorithm converts from count rate to a differential energy flux spectrum.

$$\overset{\text{counts}}{c_i} = dt\ \overset{\text{aging}}{\eta_i} \int_0^A dA \int_0^\infty \int_0^{2\pi} \int_0^\pi \overset{\text{diff flux}}{j(E,\theta,\varphi)}\ \overset{\text{detector}}{G_i(E)}\ \overset{\text{pitch angle}}{G_B(\alpha_B,\theta,\varphi)}\ \overset{\text{FOV}}{f_i(E)} \sin\theta\, d\theta\, d\varphi\, dE + \overset{\text{background}}{b}$$

Basic Concept

The algorithm generates a piecewise power law ($j_i(E) = j_{0,i}\, E^{\gamma_i}$) fit to the differential flux over adjacent energy ranges. The algorithm outputs four pairs of coefficients, $j_{0,i}$, and exponents, γ_i.



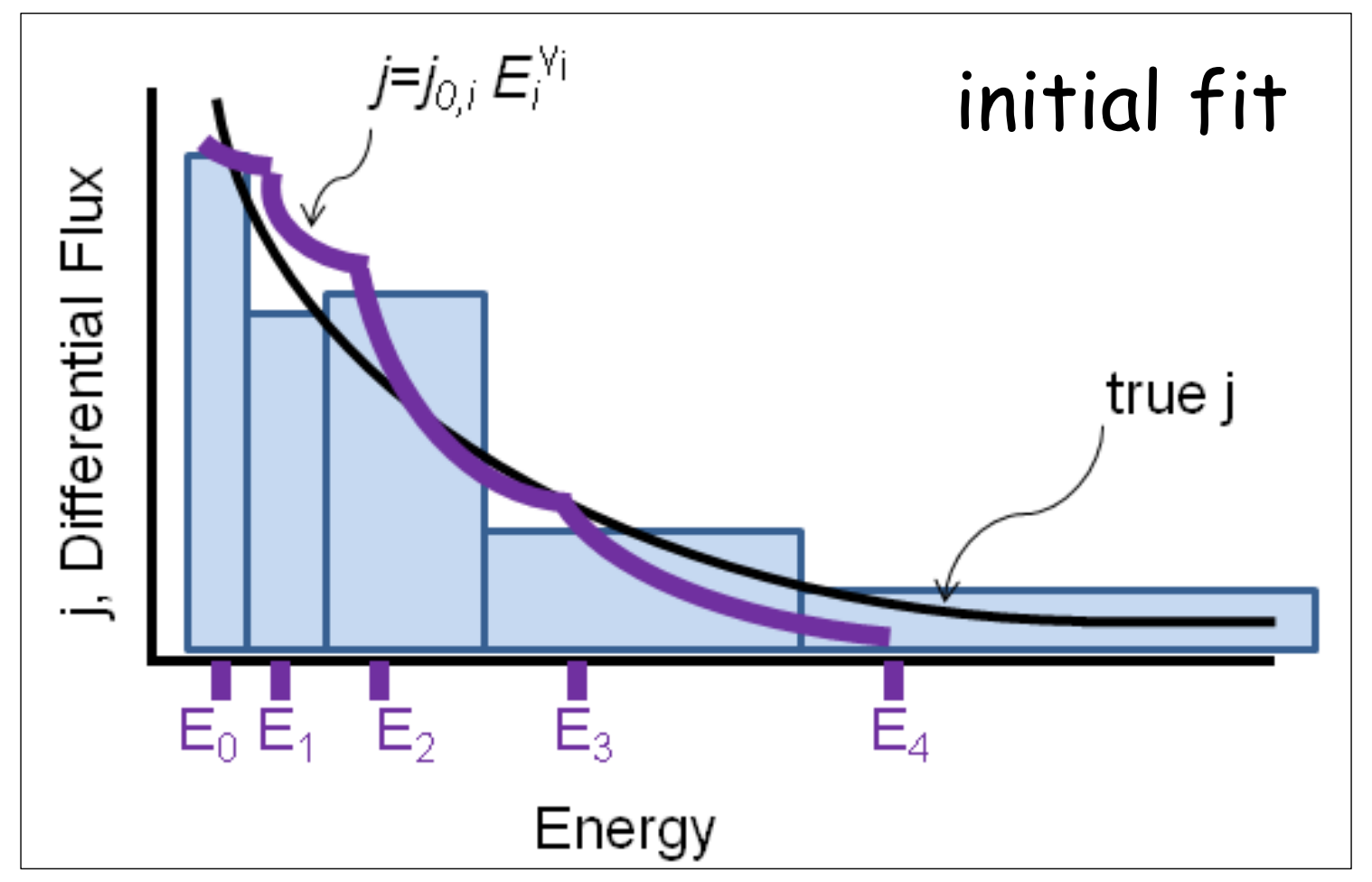
For geometric factors, $G(E)$, the count rate can be expressed as either:

$$\boxed{C = \int G(E)\ j(E)\ dE}$$

or $\boxed{C = G(E_i)\ j(E_i)\ \Delta E}$ for some "center-of-mass" energy, E_i

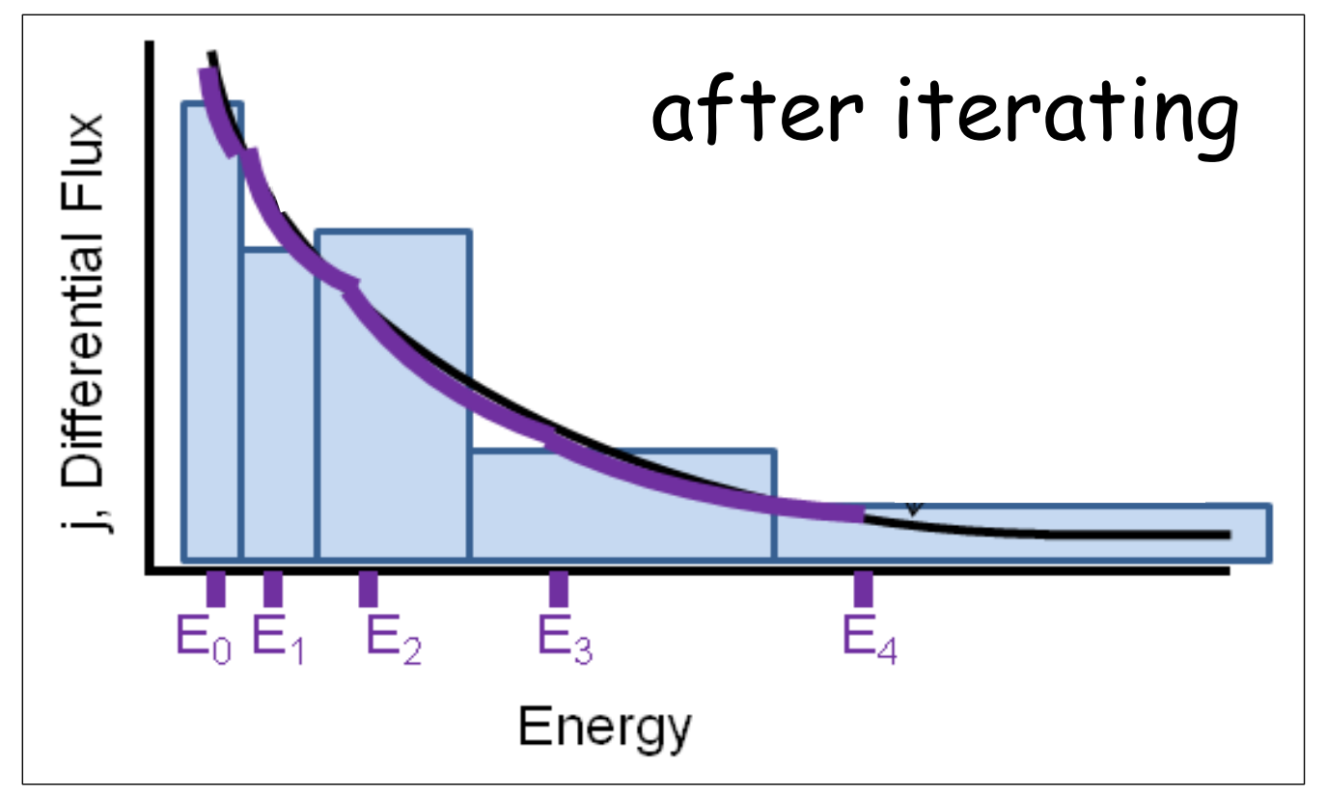
Method

1. Read in 5 channels of raw proton counts. The energy ranges of the channels overlap.



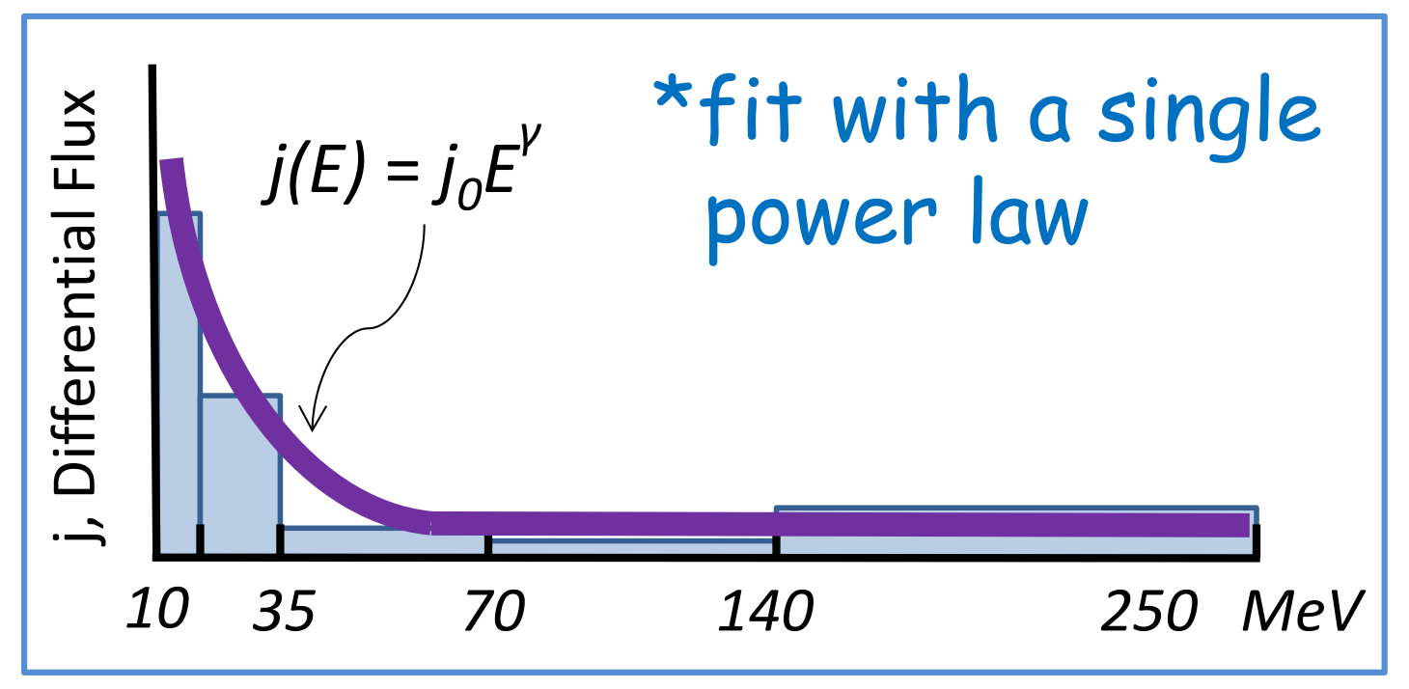
2. Generate initial estimates of the differential flux spectrum in order to convert raw counts to non-overlapping energy channels.

3. Initialize the E_i with $\sqrt{E_u E_l}$ -- the geometric mean of the E_i in adjacent channels.



4. Iteration:
   Calculate γ_i from E_i.
   Recalculate E_i using the γ_i. (Average values.)
   If errors/low counts, use single power law fit.*
   Repeat iteration until E_i change by <1%.

5. Calculate the coefficients $j_{0,I}$ from the final set of E_i and γ_i.



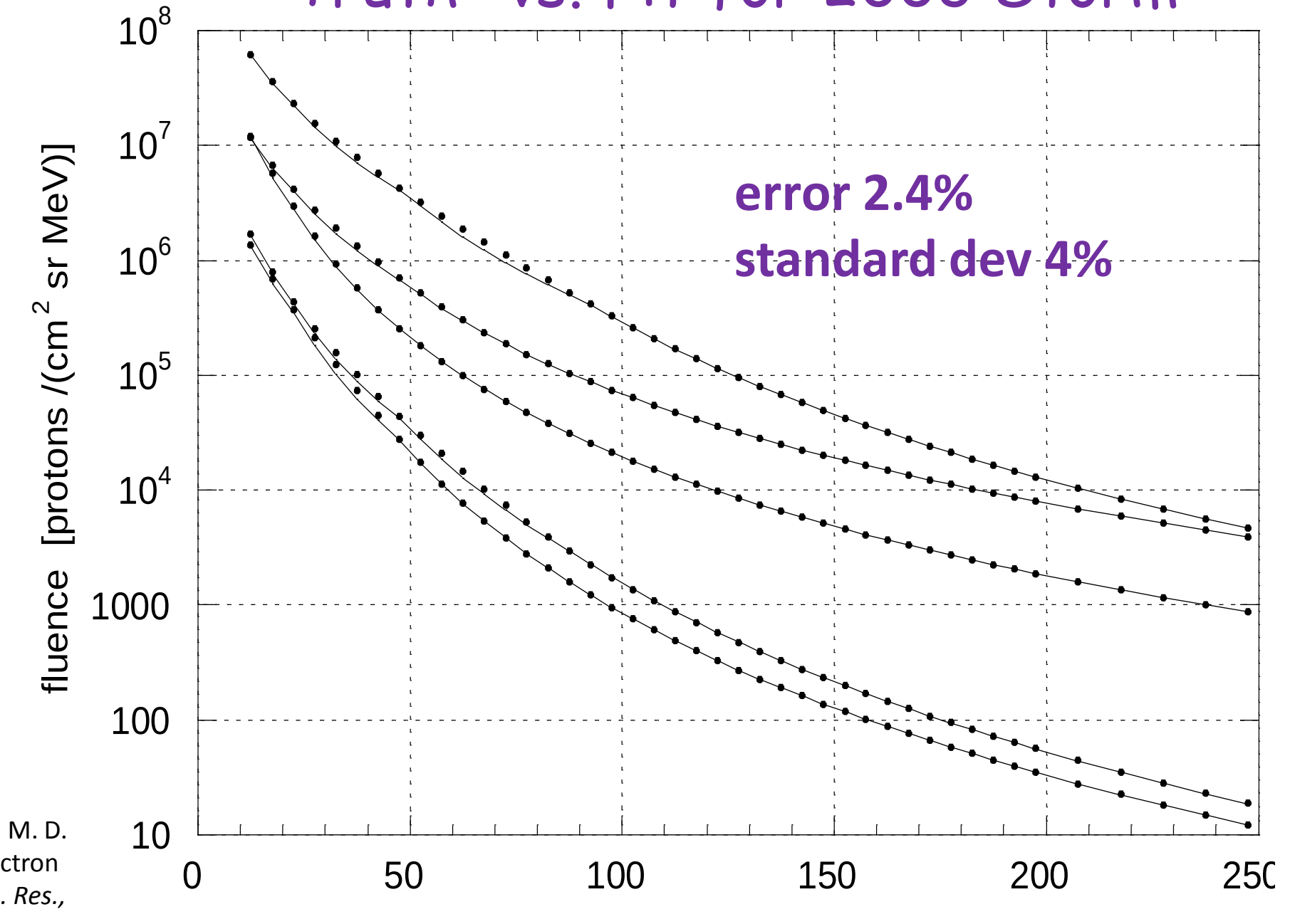
6. Extrapolate from the fits to cover the full energy range.

This technique is based on that used for the SEISS Integral Flux Algorithm for the GOES-R satellite [Rodriguez, 2009]. The method differs because the SEM-N detectors have energy-dependent geometric factors and overlapping detector channels.

Simple Validation

- Used functional forms for fluence spectra for five SEP events for the 2003 Halloween storm generated by Mewaldt et al.[1] to generate proxy counts and test algorithm.
- More validation will be done with proxy data generated from POES data.

"Truth" vs. Fit for 2003 Storm



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[1]Mewaldt, R. A., C. M. S. Cohen, A. W. Labrador, R. A. Leske, G. M. Mason, M. I. Desai, M. D. Looper, J. E. Mazur, R. S. Selesnick, and D. K. Haggerty (2005), Proton, helium, and electron spectra during the large solar particle events of October–November 2003, *J. Geophys. Res., 110*, A09S18, doi:10.1029/2005JA011038.

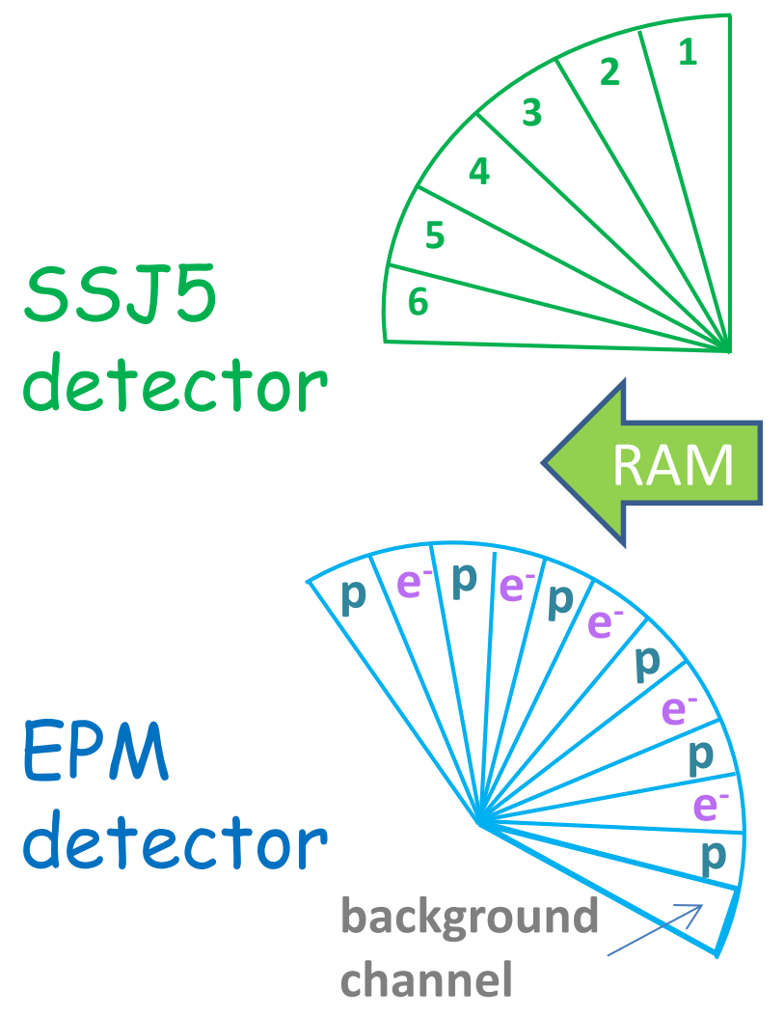
Tests with Proxy Data

- Tested algorithm by generating proxy data from POES data for 1999-2010.
- Generated "true" flux spectrum from data, created associated omni counts, added Poisson noise, and then compared algorithm output with "true spectrum".
- Average standard deviation of fits from "truth" is 30% (for non-simple fits and POES specifications).
- Can use proxy data to optimize thresholds for algorithm.

Auroral Energy Deposition Algorithm

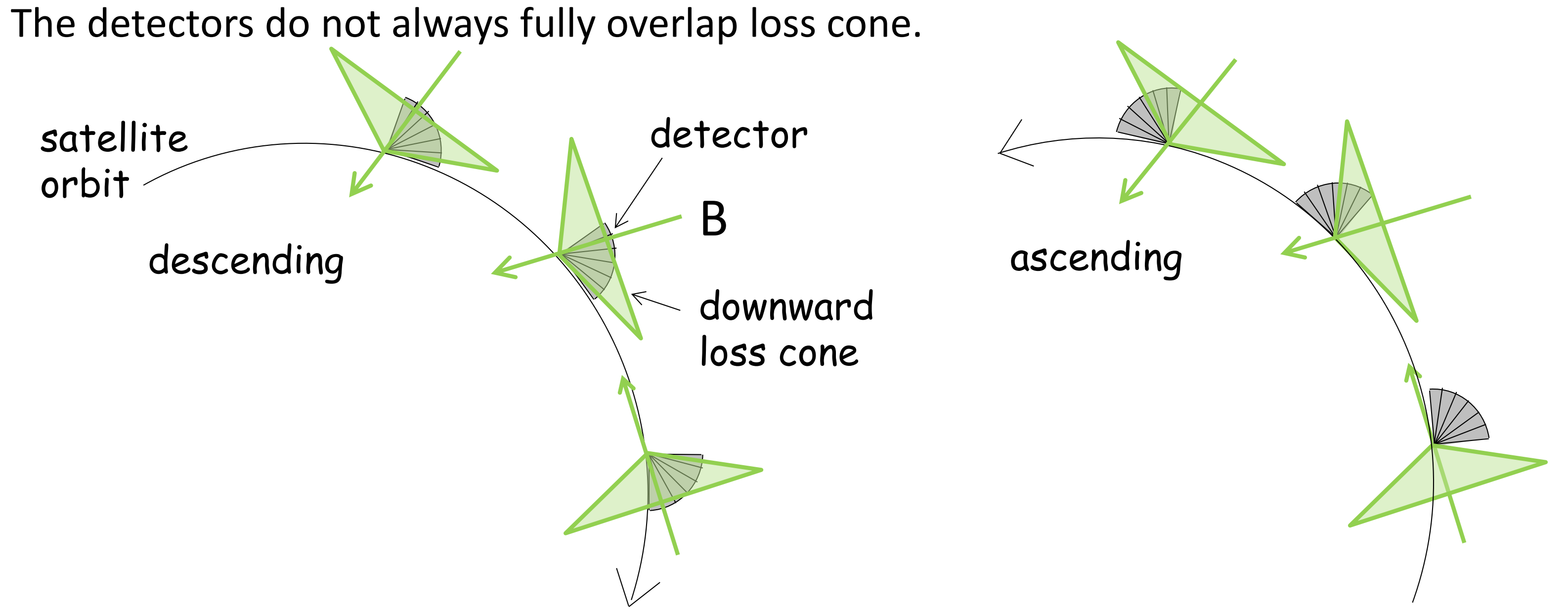
This algorithm estimates the energy flux deposited into the atmosphere by precipitating low- and medium-energy charged particles. The AED calculations include particle pitch-angle distributions. The algorithm converts differential energy flux [keV / (cm^2 s sr MeV)] to ionospheric energy deposition [W/m^2].

Method

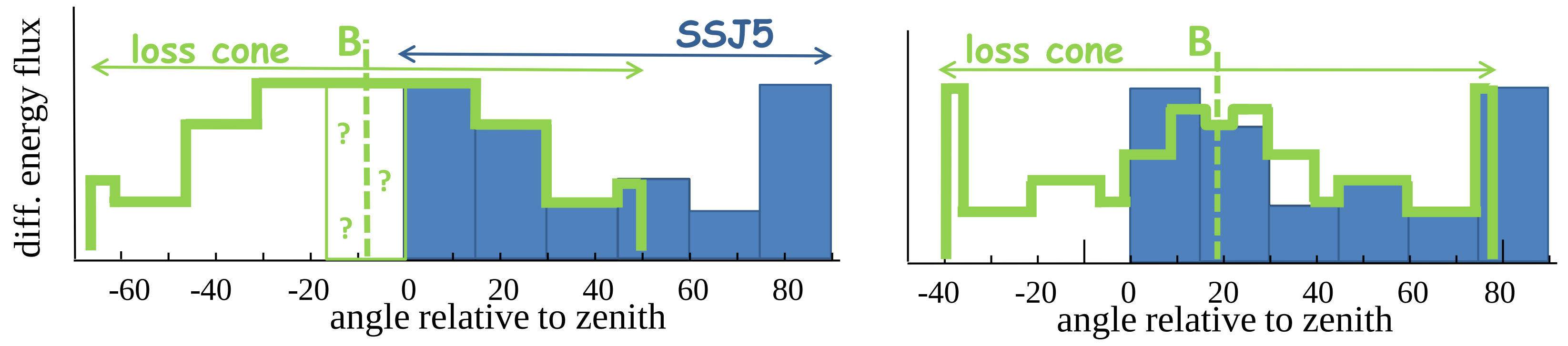


- Use **SSJ5 low energy** particle data.
  6 look directions (15˚ x 4˚)
  19 electron and proton energy levels (0.03 eV-30 keV)

  and **EPM medium energy** particle data.
  5/6 look directions (12˚ x 8˚)
  12 electron energy levels (25 keV-1 MeV)
  21 proton energy levels (30 keV-10 MeV)
- Assume that all particles in loss cone precipitate. The edge of the loss cone is given by $\alpha_0 = \sin^{-1}\sqrt{B_{sat}/B_{120}}$ and the B-field values are from the IGRF model.
- The detectors do not always fully overlap loss cone.

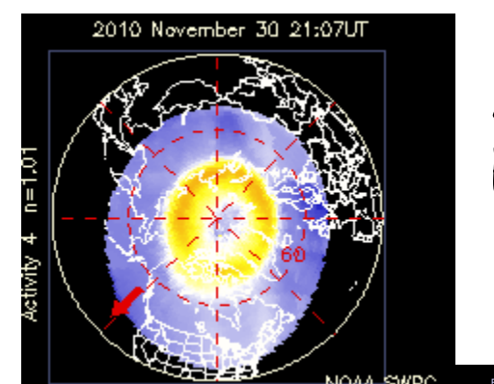


- Extrapolate over missing angles in loss cone; average as needed. Two examples:

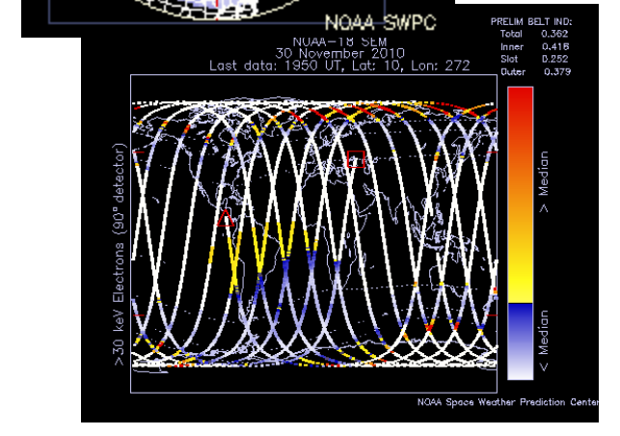


- Migrate energy flux to ionospheric altitudes ("foot-of-the-field line").
- Calculate total precipitated energy flux: $F_T = 2\pi \int_0^{\alpha_0} \cos\alpha \int_{E_{lower}}^{E_{upper}} j(E,\alpha)\, E\, dE\, d\alpha$

Current Products



Auroral Energy Flux



Radiation Belt Particle Flux

Future Products

We will reprocess POES data to produce energy flux spectra based on these routines.

We are investigating statistical methods to improve NOAA's real-time maps for auroral and radiation belt particles.