AFRL

IRENE V2.0: Coming Changes

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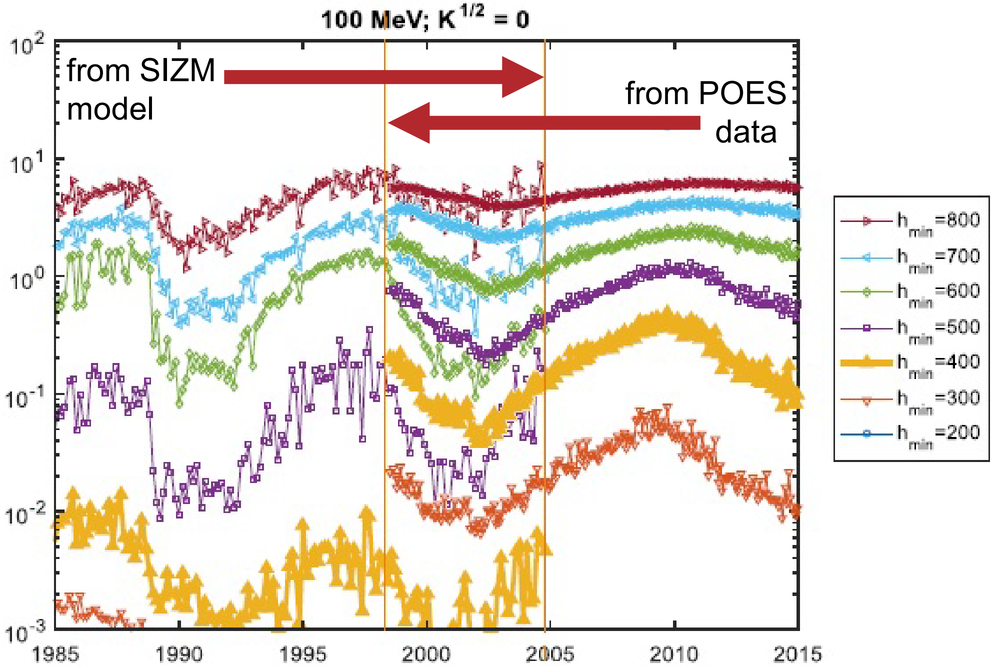
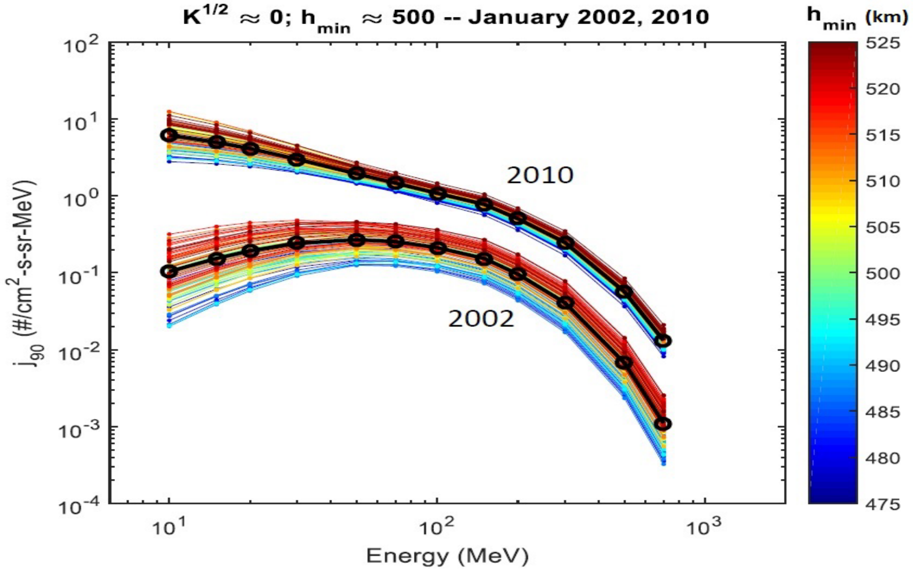
Outline

- Introduction
- Solar cycle variability
- Better marginal distributions
- Module architecture
- New ways to run the model
- Summary

Solar Cycle Variation I – Statistical Model

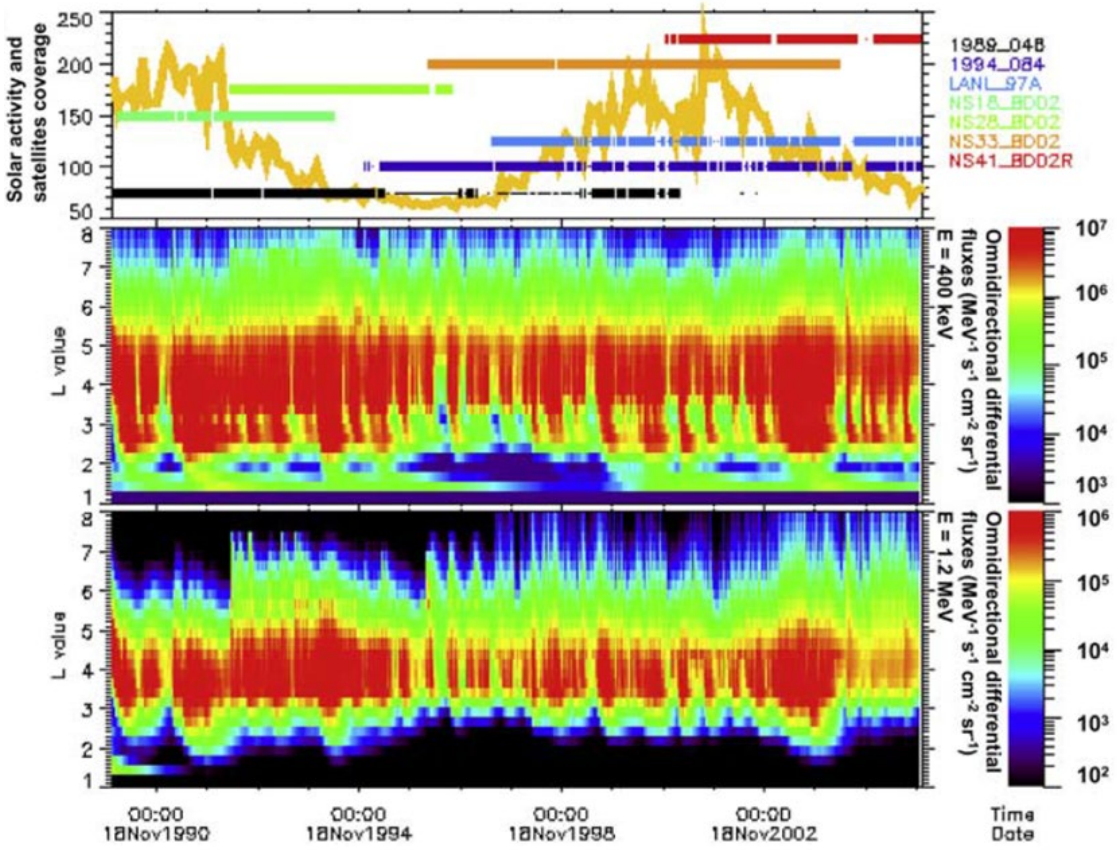
- No solar cycle dependence in AE9/AP9 currently.
  - Statistics capture ranges across all solar cycle phases.
- Users needs solar cycle dependence for trapped particles, especially protons.
  - Design for short duration LEO missions.
  - Supports use of AP9 for nowcast estimates.
- Work progressing towards solar cycle modulation of AP9:
  - Use stochastic model for future phase/intensity of solar cycle drivers of LEO protons.
  - Use models (Selesnick Inner Zone Model) and data (POES SEM-2) to relate drivers to energy- and location-dependent variability.
  - Use results to modulate AP9 flux maps (representing all data sets).





Solar Cycle Variability II: Sample Solar Cycle

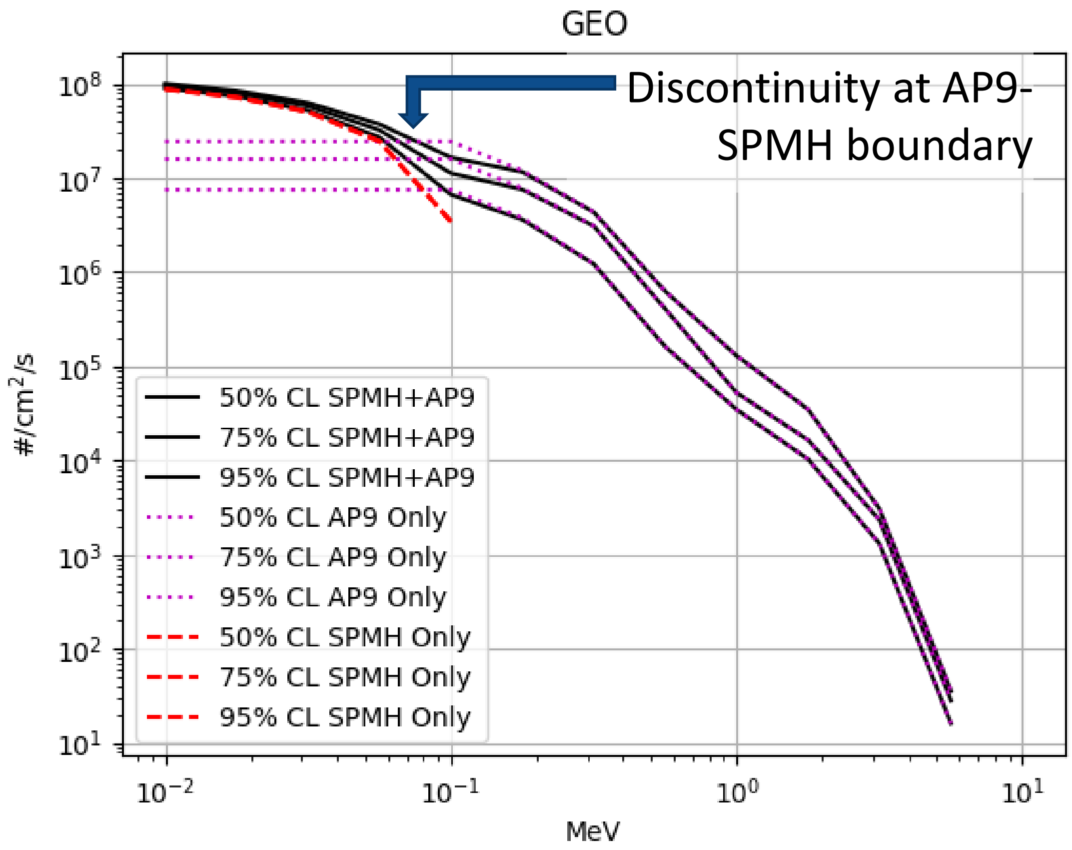
- An independent approach to solar cycle variation.
- Capture dynamics of realistic 11+ year solar cycle via data assimilative reanalysis.
- “Fly through” this simulated dynamic environment as a check on Monte Carlo results.



From Maget et al., Space Weather, 2007

Better marginal distributions

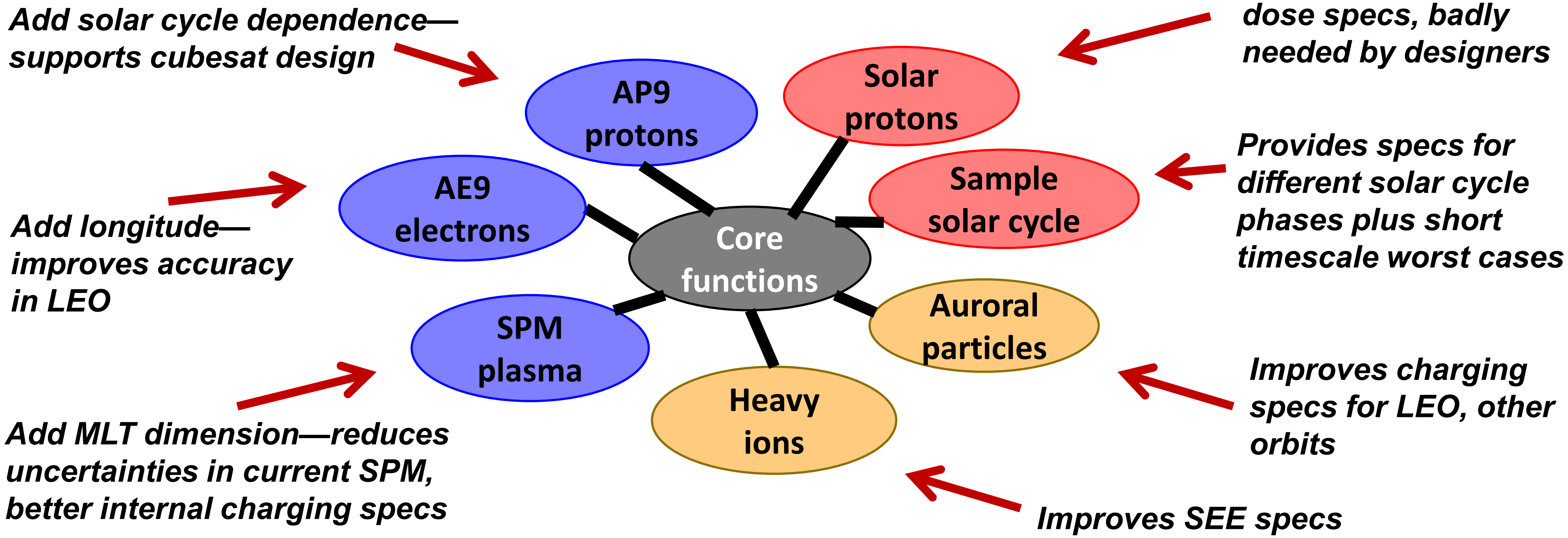
- Currently AE9 uses Weibull distributions with 2 parameters, while all other models use LogNormal.
- This creates statistical discontinuities, which we can, at best, stitch together at run time (see figure at right).
- We would prefer a new framework that allows a smooth transition between Weibull and Log-Normal while retaining a relatively simple description of uncertainty.
- Our new approach uses tables of percentiles to describe the central part of the distribution, and a generalized gamma distribution for the tails.
- The generalized gamma can fit both Weibull and log-normal shapes.
- Errors on the marginal distribution are still represented using the existing perturbations to the 50th and 95th percentiles, but these perturbations are converted to a power-law transform applied to the entire distribution.



Version 2.0 Modules

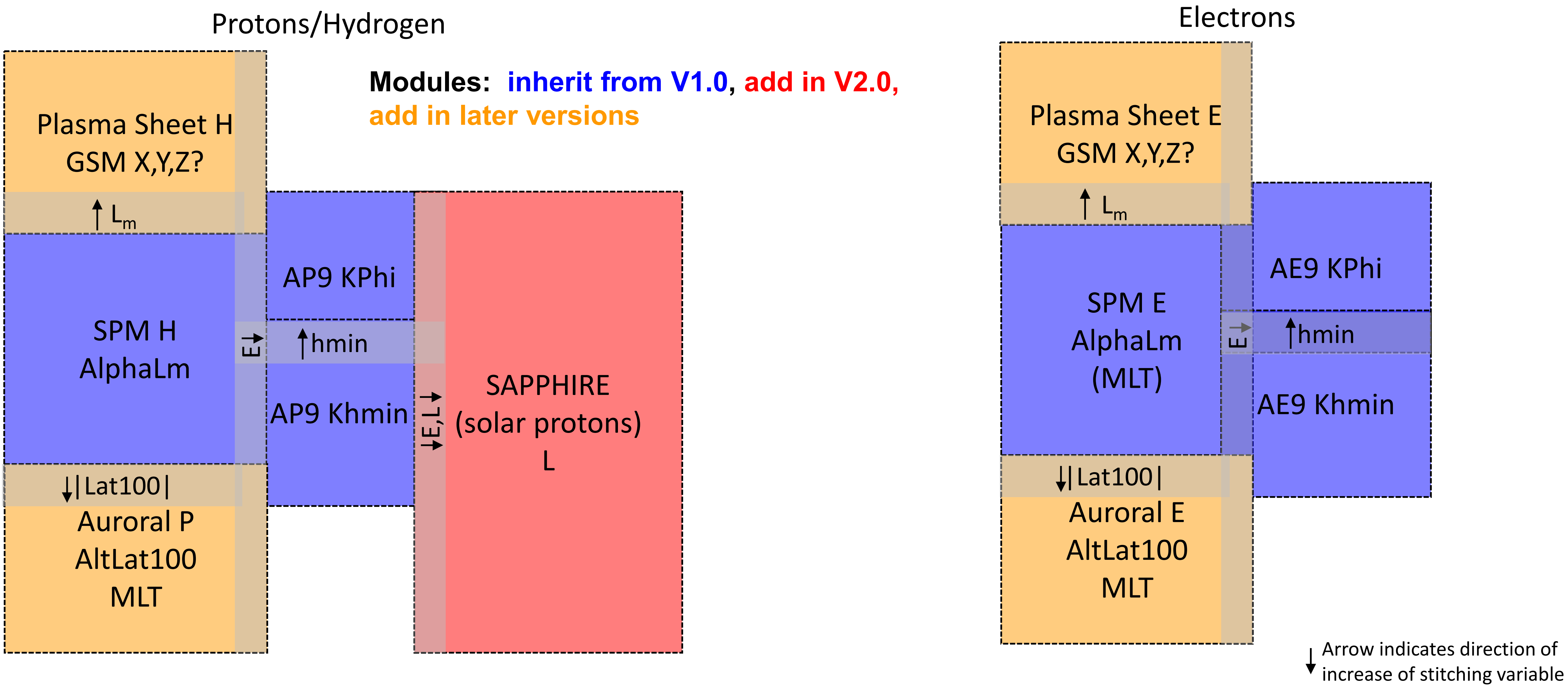
- The module architecture is a generalization/combination of existing pieces and new pieces.
- In V1.x, the AE9/AP9 high (K-Phi) and low (K-h_{min}) grids are stitched together at runtime, while the high (AE9/AP9) and low (SPM) energy spectra are stitched in post processing.
- In V2.0, all modules will be stitched at run time.

Modules: inherit from V1.0, add in V2.0, add in later versions



Future Modules and how they stitch together

Modules: **inherit from V1.0**, **add in V2.0**, **add in later versions**

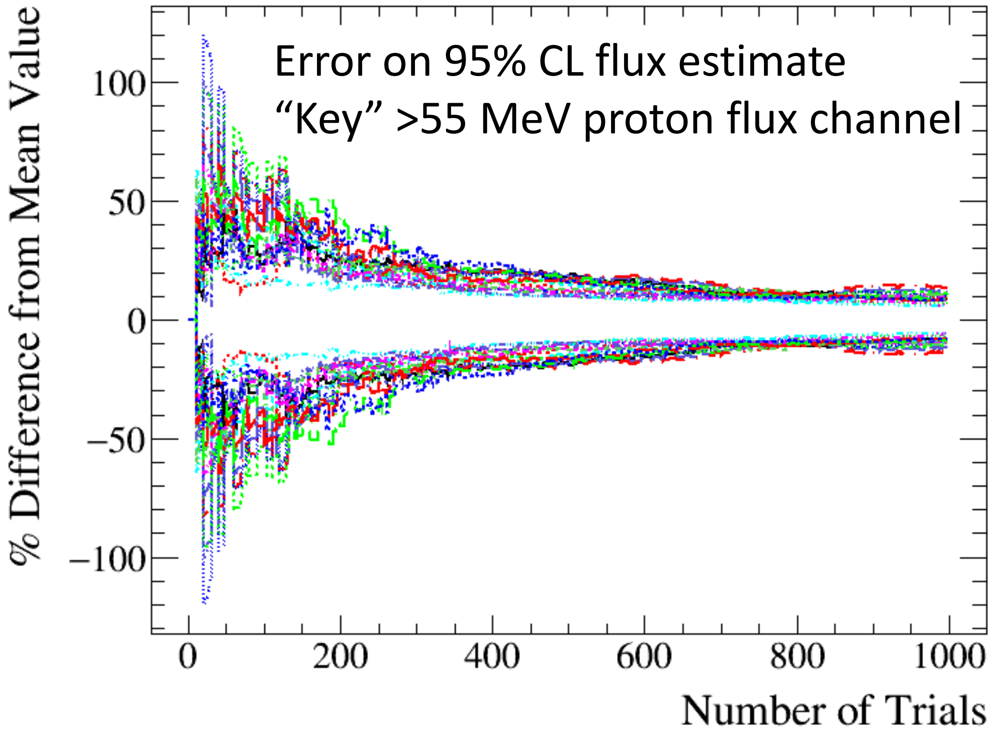


New ways to run the model

- In V1.x, one can request flux or dose and associated accumulations.
- In V2.x, a new approach to runs is provided:
  - Specify a type of output: differential flux, integral flux, or kernel transform.
  - Specify an accumulation scheme: none, mean, fluence, running averages.
  - Specify an output cadence: list of times or time step.
  - Type of runs: mean, perturbed mean, Monte Carlo, static percentile, etc.
- Model automatically determines what modules to run based on output request.
- Example use cases:
  - Total Dose: kernel applied to electron/proton fluence, combined (multi-species kernels).
  - Displacement Damage: kernel applied to fluence (mean env).
  - Average differential proton/electron flux (static mean).
  - Mission integral electron fluence at 95% CL (perturbed mean).
  - Worst case proton / (solar) ion SEE rate (Monte Carlo mode, boxcar averaging, SEE kernel).
  - Mission-average proton SEE rate at 95% CL (perturbed mean, SEE kernel).
  - Worst-case internal charging: electron current vs depth, with boxcar averaging (Monte Carlo mode, IC kernel).
  - Integral proton in fluence in 80^{th} percentile elevated environment (static percentile env).
  - Wide Differential Flux time series (mean env).
  - Interval Dose: kernel applied to boxcar.

Tracking uncertainty from finite scenario count

- To date, we recommend 40 scenarios for coarse orbit trades, 200 scenarios for typical specification building, and 999 scenarios for crewed missions. These numbers are designed to prevent unnecessary Perturbed Mean and Monte Carlo calculations to obtain a good working precision.
- Using the Maritz-Jarrett formulation, we can estimate the error on any confidence level computed from a finite sample of scenarios.
- In V2.0, we will introduce the ability to compute and output those error estimates.
- We will also introduce the ability to flag “key” confidence level outputs with a desired precision and run as many scenarios as required to meet that precision.
- We might also be able to implement random sampling in the time domain for fluence-type quantities. For example, this would allow one to randomly sample a 10-year mission until a desired precision is met, rather than running a single week at dense time stepping and scaling up to 10 years.



Maritz-Jarrett estimated error versus number of scenarios. Illustration courtesy of Scott Davis, Aerospace.

Summary

- There will be two ways to represent solar cycle variability: statistical model and sample solar cycle.
- Marginal distributions will be more flexible and have fewer/smaller discontinuities.
- Modules will allow more particle populations to be included and reduce discontinuities.
- There will be new ways to run the model.
- We will add the ability to run as many scenarios as needed to obtain a desired precision on key confidence levels.

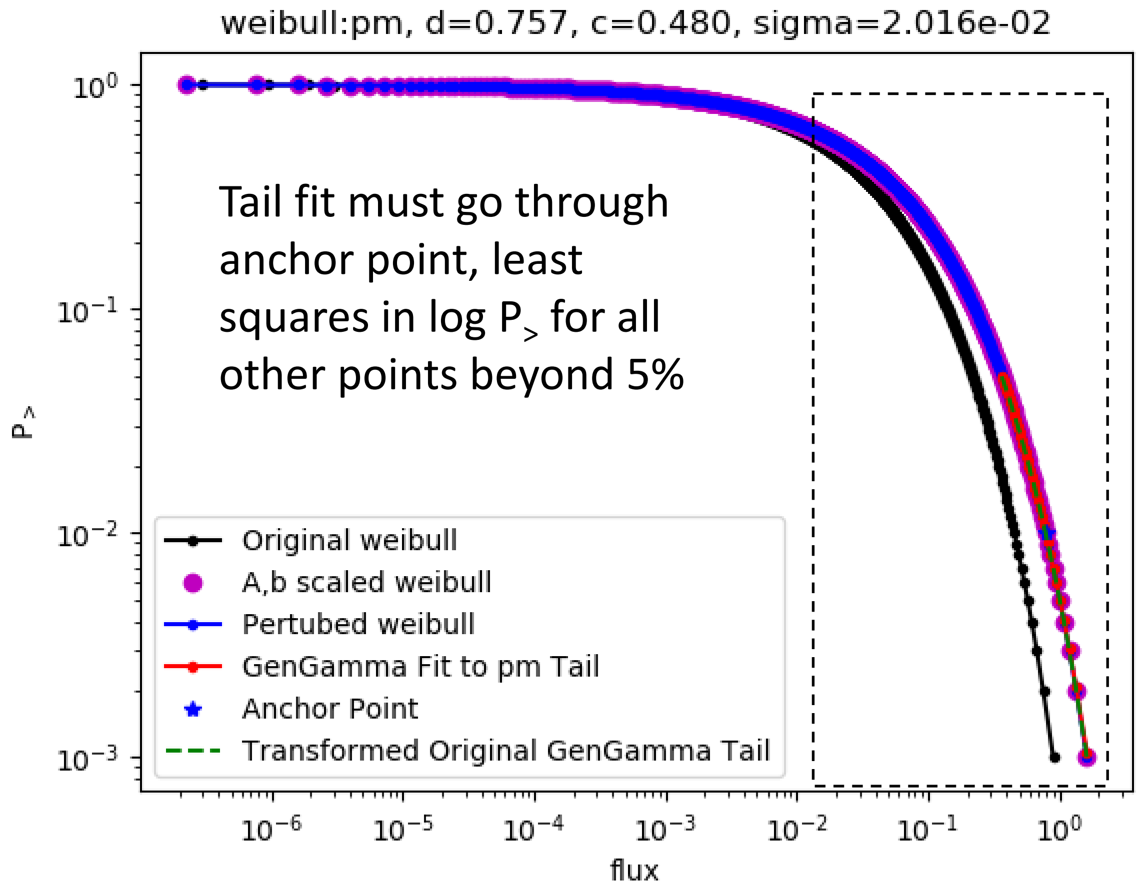
BACKUPS

Marginal distribution math

- At each grid point, we have a table of percentiles: $\vec{m} \in \{F(m_i) = p_i\}$
  - m_i is the flux at percentile p_i.
  - m_{50} denotes the median, and m_{95} denotes the 95th percentile.
- Error is represented on transformed variables:
  - $\theta_1 = \ln m_{50}, \theta_2 = \ln(m_{95} - m_{50})$.
  - Global error matrix $\underline{\underline{S}}_\Theta$ tracks correlated errors at all grid points for θ_1 and θ_2.
  - Perturb all θ using: $\vec{\Theta}' = \vec{\Theta} + \underline{\underline{S}}_\Theta \vec{\varepsilon}$, then obtain m'_{50} and m'_{95} at each grid point.
- Assume a power-law perturbation function: $m'_i = A{m_i}^b$
  - $b = \ln \frac{m'_{50}}{m'_{95}} / \ln \frac{m_{50}}{m_{95}}, A = \frac{m'_{50}}{{m_{50}}^b}$
  - Apply this transform to all percentiles: $\vec{m}' \in \left\{F'(m'_i) = F'\left(A{m_i}^b\right) = p_i\right\}$
- Tail:
  - Original generalized gamma is: $F(x) = \gamma\left(\frac{d}{c}, \left(\frac{x}{\sigma}\right)^c\right) / \Gamma\left(\frac{d}{c}\right)$
  - Weibull when $\frac{d}{c} = 1$, log-normal as $\frac{d}{c} \to \infty$
  - Perturbed is $F'\left(x' = Ax^b\right) = \gamma\left(\frac{d'}{c'}, \left(\frac{x'}{\sigma'}\right)^{c'}\right) / \Gamma\left(\frac{d'}{c'}\right)$, $\sigma' = A\sigma^b, c' = c/b, d' = d/b, \frac{d'}{c'} = \frac{d}{c}$

Marginal distribution tail fitting and perturbation

- In this example, we choose a real Weibull distribution from AE9 (black) and fit a gamma distribution to the tail.
- We perturb the 50th and 95th percentile scheme from IREVEN V1.x and then extract parameters of a power-law transform and apply that power law to the entire distribution and to the Weibull parameters (magenta, blue).
- We also perform a tail fit to the perturbed points with the generalized gamma (red).
- Both generalized gamma fits are anchored to a fixed percentile (blue star, 99th percentile).
- We apply the power law transform to the unperturbed generalized gamma distribution parameters (green) and show that it is in good agreement with the fit to the perturbed tail.



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