The IRENE Next Generation Radiation Specification Model: Challenges

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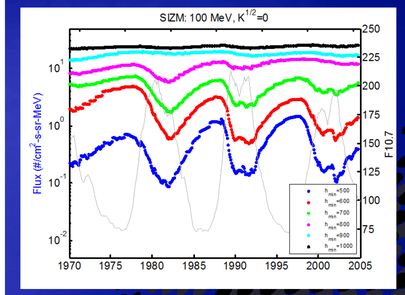
Introduction

The AE9/AP9/SPM model (to be renamed the International Radiation Environment Near Earth, IRENE) has now been released to the global scientific and satellite design communities. However, many challenges remain after version 1.0. We discuss several of these challenges: incorporating new data, solar cycle variation in the Monte Carlo model, the sample solar cycle, extending the internal magnetic field model far into the future, merging trapped with solar particle models, international collaboration. For each challenge, we put it into context and describe our strategies for progress.

Low Altitude Behavior:

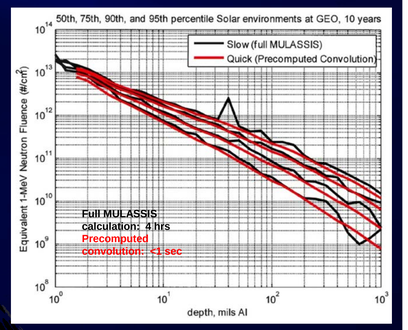


LEO protons vary systematically with the solar cycle
- No comprehensive, quantitative empirical model of this variation exists
- We plan to use SIZM + POES
- Allow model statistical parameters to vary with F10.7
- Generate Monte Carlo scenarios of F10.7

LEO Electrons vary with longitude
- Depends on level of magnetic activity filling the drift loss cone
- Will require addition of 4th dimension (dipole longitude) to $E/K/h_{min}$ coordinate system

Arbitrary Radiation Effects:

- AE9/AP9 currently only provides total dose via ShielDose2 for idealized shielding
- Users need to consider other effects:
  - Specific shielding geometry or material
  - Displacement damage
  - Single Event Effects (SEE)
  - Internal charging
- Some of these phenomena can be reduced to linear transfer functions (Greens functions)
  - We are developing a generic "Kernel" capability to allow a user-supplied effect via the Greens function
  - Applies only to linear effects
  - First kernel: displacement damage in Si behind spherical Al shields
  - Second kernel: Proton SEE via Weibull response + Al Shielding



from O'Brien and Kwan, Aerospace report TOR-2013-00529, 2013

Data Inadequacies:

Plasma composition
- Helium, Oxygen only from Polar CAMMICE/MICS
- Looking at AMPTE, CRRES, Van Allen Probes

Inner zone electrons
- Van Allen Probes see no electrons above ~700 keV
- Past measurements are not clear on this
- Is this a temporary state, or is this typical?

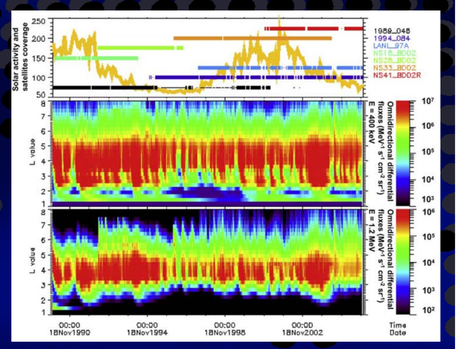
Low altitude gradients are difficult to measure
- Small differences in local pitch angle at high altitude lead to large differences in flux at low altitude
- Low altitude flux is often confined to very near 90° pitch angle

Data does not cover everywhere
- Physics-based and assimilative models can teach us how to extrapolate

Data cannot provide adequate correlation in space and time
- Physics-based and assimilative models can provide correlations

Sample Solar Cycle:

- 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
- Use the sample solar cycle to improve correlation matrices that drive Monte Carlo dynamics
- Use the sample solar cycle to help "fill in" flux maps where observations are missing



from Maget et al., *Space Weather*, 2007

Integrating Solar Protons:

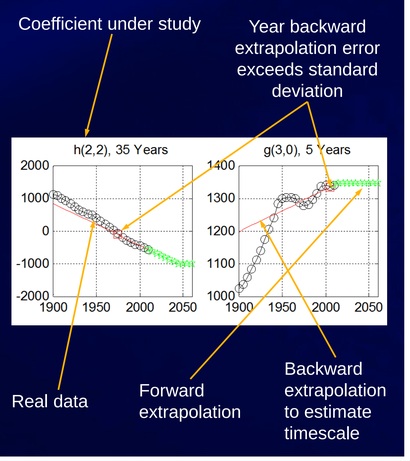
- Solar protons contribute to proton effects addressed by AP9:
  - Total Ionizing Dose
  - Displacement Damage
  - Single Event Effects
- Statistical laws disallow adding 95th percentiles from AP9 and a solar model to obtain a combined 95th percentile
  - The statistical distributions must be combined before computing percentiles
  - Combination must include dynamics for Single Event Effects
- We are working with ESA to resolve this problem
  - Developing a Monte-Carlo method for solar protons
  - We will combine that with a geomagnetic cutoff model to limit solar proton access
  - This will enhance mean, perturbed mean, and Monte Carlo runs of AP9

IGRF Extrapolation:

- IGRF only extrapolates 5 years
- Mission planners plan up to 25 years ahead
- We need a way to extrapolate IGRF many years into the future

- Physics-based prediction is very complicated because the Earth's dynamo is chaotic

- One possible empirical approach:
  - Extrapolate each coefficient N years into the future
  - N is unique for each coefficient
  - N depends on how well a backward linear projection matches historical data



Plasma Coordinate Systems:

- All plasma are currently modeled in a $E/\alpha/L_m$ system with no MLT dependence

- We will add a 4th dimension for MLT (e.g., to address Sun-synchronous orbits)

- We also will eventually need auroral and plasma sheet coordinate systems and potentially a magnetosheath system

Stitching Domains:

- AE9/AP9 has 3 distinct domains:
  - High altitude energetic particles: $E/K/\Phi$ grid, $E > \sim 40$ keV
  - Low altitude energetic particles: $E/K/h_{min}$ grid, $E > \sim 40$ keV
  - Single plasma grid: $E/\alpha/L_m$ grid, $E < \sim 40$ keV
- The high-low altitude stitching is done when the model data tables are computed before runtime
- The plasma – energetic particle stitching is done in post-processing after runtime:
  - Potentially invalid statistics!
  - Mismatch for perturbed means
- We need to switch to a stitching approach that applies at run time
- This will require extending Monte Carlo capabilities to plasma energies (currently only available for energetic particles)
- This is a significant architecture change

Summary:

A number of significant challenges remain in developing a global specification model for the Earth's radiation belts. The AFRL-led IRENE team is working to address these challenges with collaboration from our international partners.

The next release of the model, version 1.5, will incorporate new data sets, including some data from the Van Allen Probes. Version 2.0 will incorporate more of the Van Allen data, along with other data sets, and will address the challenges discussed here.