The AE9/AP9 Next Generation Radiation Specification Models – Challenges

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Outline

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- Data – Model Comparisons
- Integrating Solar Protons
- Sample Solar Cycle
- Arbitrary Radiation Effects
- IGRF extrapolation
- Stitching Domains
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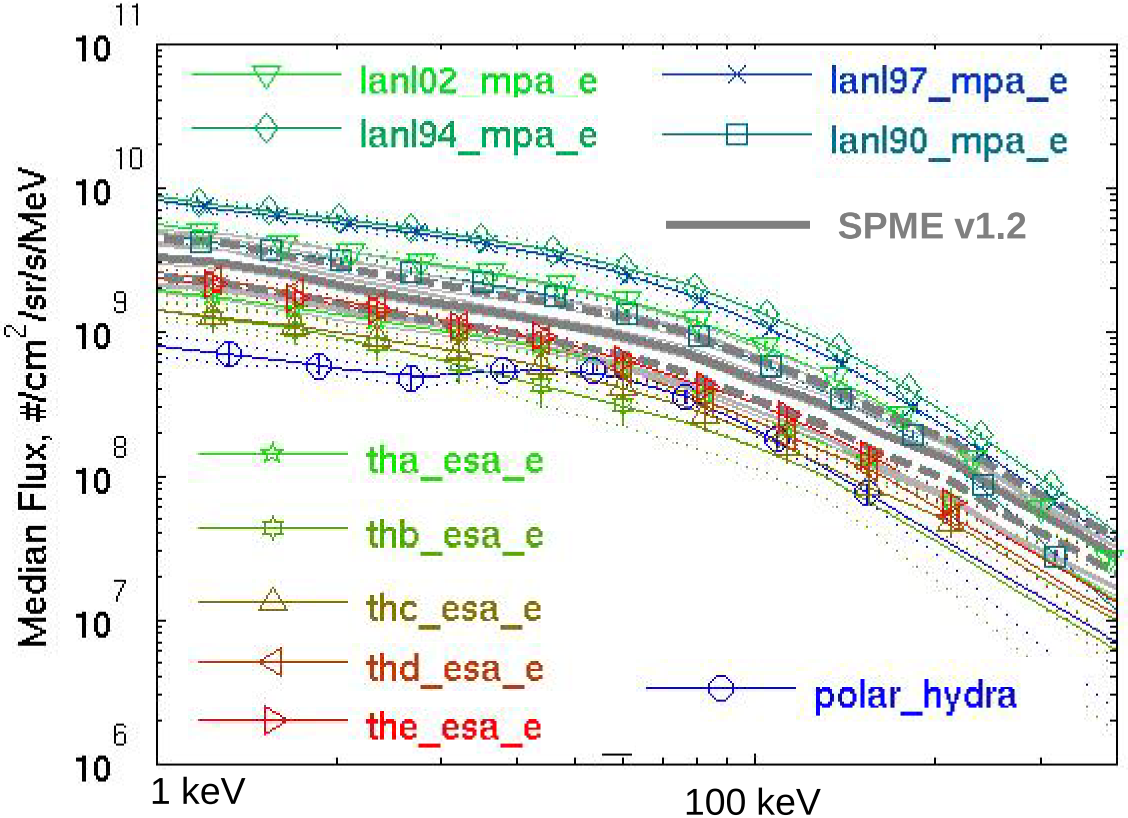
Data Inadequacies

- 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

Single-Data-Set vs Model

Median and 1-σ for each data set and the model



Electron Plasma Model (SPME), v1.2
L_m=7, α=35

- It is common to compare a single data set to AE9/AP9 and draw some kind of conclusion, e.g., "AP9 is too high"
- This is typically incorrect
- In the example at left from SPME:
  - The data sets spread over about a factor of 10
  - The model error is about a factor of 3
  - The model error is *small* because there are many data sets
- If the model error covered the spread of the data *it would never shrink no matter how many data sets we added*
- The model error bars are designed so that a model update with a new data set will still fall within the error bars of the prior model release

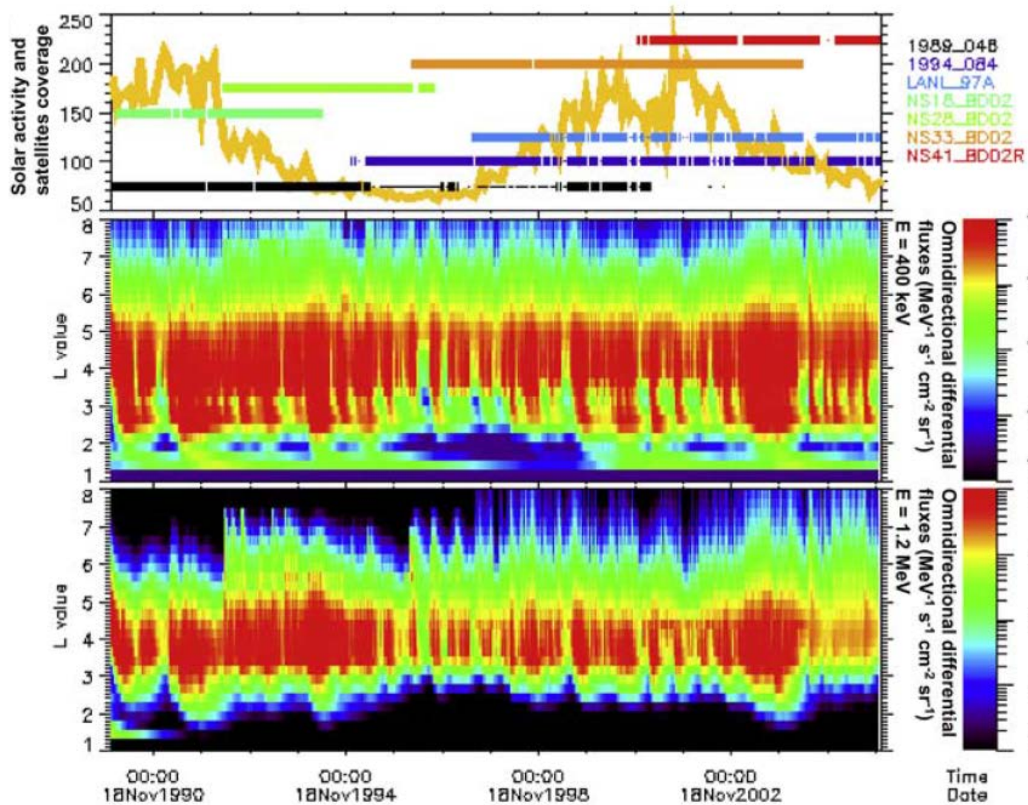
We do not expect any individual data set to fall within the model error bars

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

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

Arbitrary Radiation Effects

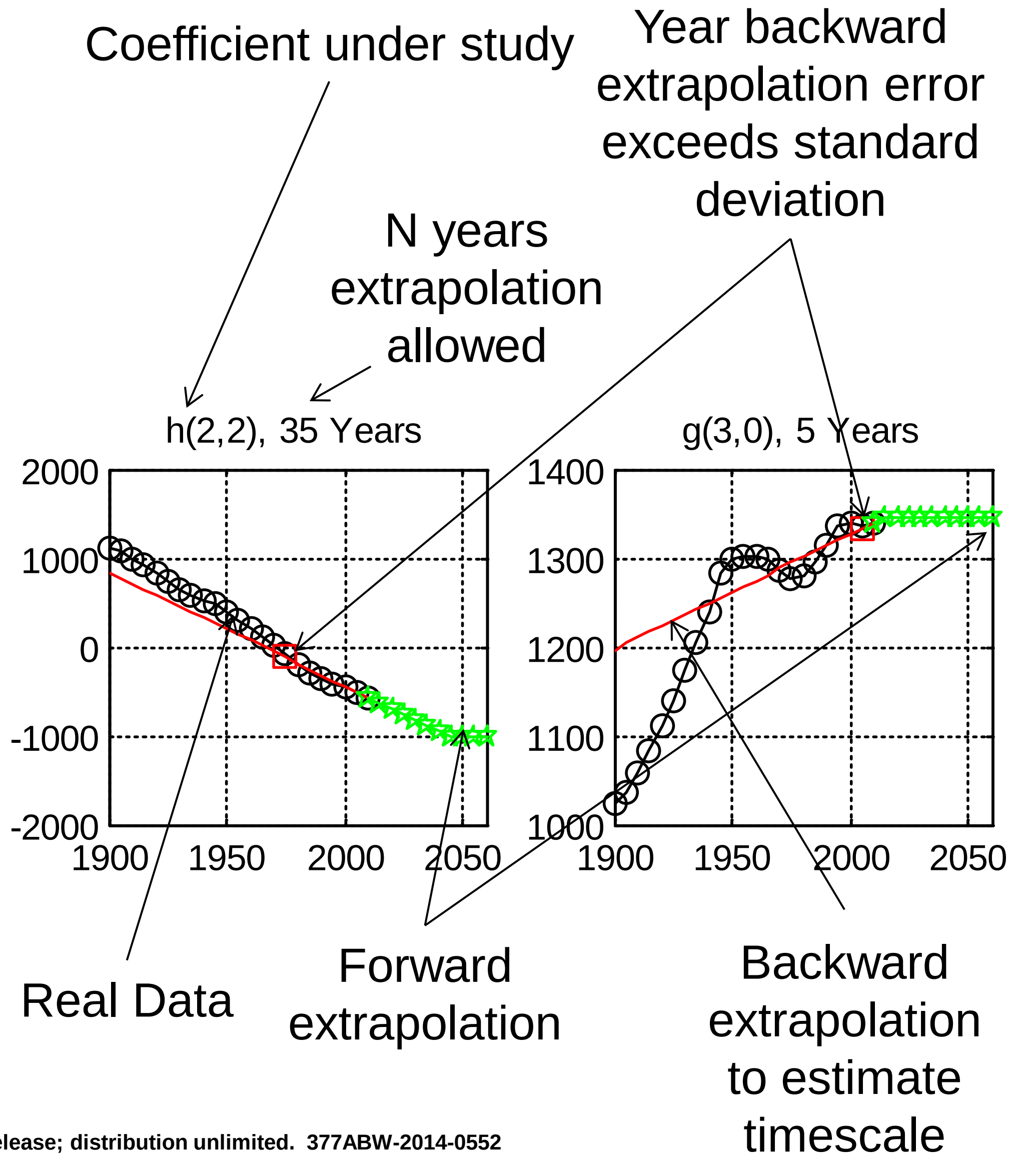
- AE9/AP9 currently only provides Total Dose via ShielDose2 for idealized shielding
- Users need to consider other effects:
  - Specific shielding geometry or material
  - Displacement Damage
  - Single Event Effects
  - Internal charging
- Some of these phenomena can be reduced to linear transfer functions (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

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 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



Stitching Domains

- AE9/AP9 has 3 distinct domains:
  - High altitude energetic particles: E/K/Φ grid, E > ~40 keV
  - Low altitude energetic particles: E/K/h_{min} grid, E > ~40 keV
  - Single plasma grid: E/α_{eq}/L_m grid, E < ~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

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

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

Miscellaneous

- AE9/AP9 has an ad-hoc outer limit defined by Shabansky orbits in Olson-Pfitzer Quiet
  - The flux there is not zero, but how do we represent it?
  - How should we define the Shabansky limit? It depends on K and Φ
- The AE9/AP9 software can be very slow
  - Speed up via parallelization
  - Speed up via optimization (faster sparse matrices?)

Summary

- AE9/AP9 exhibits a number of difficult challenges
- We are working on some, and have ideas for how to address others
- We cannot do it all: funds, manpower, expertise

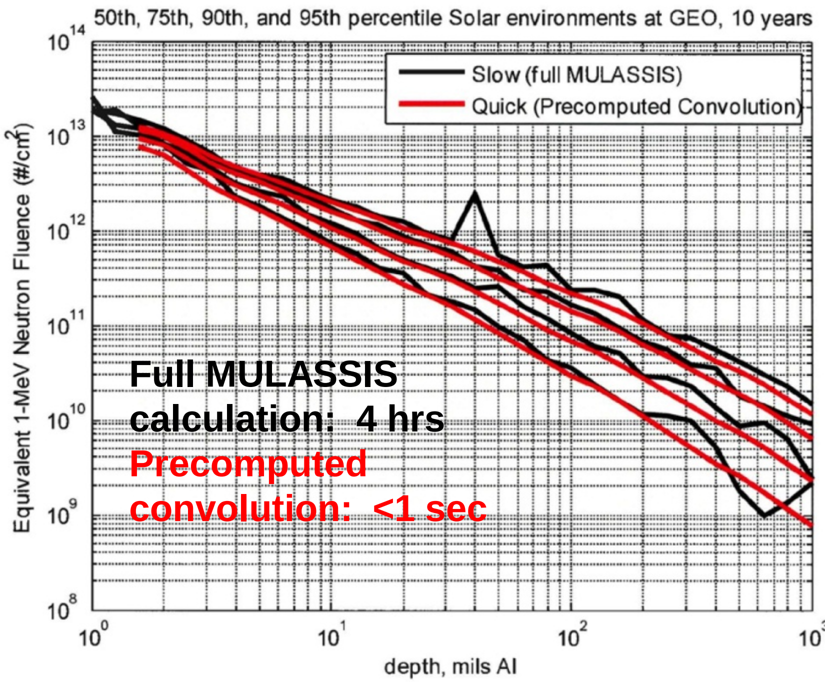
- Collaborate with us, please!

BACKUP MATERIAL

Kernel-Based Effects Calculation (V1.5)

- V1.5 will include AE9/AP9 capability to use independently-calculated radiation effects for faster effects results in the AE9/AP9 environment:
  - User precomputes desired effect vs. depth/particle/energy for a particular material/geometry/component, using independent particle simulation code
  - Results are formatted as a “kernel” for import into AE9/AP9/SPM
  - AE9/AP9/SPM environment plus effects kernel yields rapid calculations of specific effects

- Sample kernel for single event effects is in development
- Provides ability to rapidly obtain AE9/AP9 environment effects for specific components



Points of Contact

- Comments, questions, etc. are welcome and encouraged!
- Please send feedback to (copy all):
  - Bob Johnston, Air Force Research Laboratory, AFRL.RVBXR.AE9.AP9.Org.Mbx@kirtland.af.mil
  - Paul O'Brien, Aerospace Corporation, paul.obrien@aero.org
  - Gregory Ginet, MIT Lincoln Laboratory, gregory.ginet@ll.mit.edu
- Information and discussion forum available on NASA SET website:

  http://lws-set.gsfc.nasa.gov/radiation_model_user_forum.html
- V1 code will eventually be available on the NASA SET website
  - In the meantime contact Gregory Ginet, MIT Lincoln Laboratory, gregory.ginet@ll.mit.edu

Thank You