

## AE9/AP9-IRENE Radiation Environment Model: Future Development Plans and Needs

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# Outline

Background on AE9/AP9-IRENE
Model needs
Data set needs
Conclusion

#### What is AE9/AP9-IRENE?

- AE9/AP9-IRENE specifies the natural trapped radiation environment for satellite design and mission planning
- It improves on legacy models to meet modern design community needs:
  - Uses 45 long duration, high quality data sets
  - Full energy and spatial coverage—plasma added
  - Introduces data-based uncertainties and statistics for design margins (e.g., 95<sup>th</sup> percentile)
  - Dynamic scenarios provide worst case estimates for hazards (e.g., SEEs)
  - Architecture supports routine updates, maintainability, third party applications
- V1.00 released in 2012, V1.55 in April 2019





#### Version 2.0 Modules

- The module architecture is a generalization/combination of existing pieces
  - K-h<sub>min</sub>/K-Phi stitching (runtime)
  - SPM/AX9 stitching (post-processing  $\rightarrow$  runtime)
  - ESA framework for combining trapped + solar + GCR (post-processing  $\rightarrow$  runtime)



#### 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
- What we need:
  - 10 eV 10 MeV electrons
  - 10 eV 1 GeV protons
  - 10 eV 200 keV He+, O+
  - Data assimilative
  - At least 11 years
  - Prefer one giant simulation with all the above
  - Simulations addressing a subset can still inform correlation models and templates



From Maget et al., Space Weather, 2007

### Solar Cycle Variation of LEO Protons

- No solar cycle dependence in AE9/AP9 currently
  - Statistics capture ranges across all solar cycle phases
- Users needs solar cycle dependence for trapped 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)
- What we need:
  - More information on altitude gradients
  - LEO data sets, energy & pitch angle resolved, at least ~20 years duration



#### Fast, Compact LEO Electron Coordinates

- Intended to capture drift loss cone structure
- Must account for longitude structure, may also need to account for MLT dependence
- Must run quickly no run-time drift shell tracing; use neural networks or other speedups instead
- Demonstrate on LEO data set like DEMETER or POES



#### Low-Altitude Electron Gradients

- At plasma and radiation belt energies, we do not have a great ability to model the altitude gradient below ~1000 km.
- This is due in part to paucity of data, which could be remedied with DEMETER and other LEO data sources
- We expect a modeling component, e.g., the Selesnick drift-scattering model, will be needed.
- What we need:
  - Model providing a realistic description of LEO electron variability as a function of energy 10 eV to 10 MeV (especially 10 keV to 10 MeV) and location, 100-1000 km
  - Could be done with a 1-year simulation, or simulation of several storm periods plus a few quiet periods.
  - Intended use: building LEO electron templates.



#### Statistical Alternative to Weibull-LogNormal Dichotomoy

- 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
- We would prefer a new framework that allows a smooth transition between Weibull and Log-Normal
- Note that the model tracks uncertainty on the statistical parameters via error covariance
  - A naïve table of N percentiles will have N(N+1)/2 error parameters at every grid point
  - Table-of-percentiles approach with a simplified error covariance might work
  - Alternately, a new analytical framework that somehow merges Weibull and LogNormal could work
- Performance is an issue, both in terms of number of parameters and speed of computation

PlasmaSheetE GSM X,Y,Z? L <sub>m</sub>		
SPME AlphaLm (MLT)	E 🛉	AE9 KPhi thmin AE9 Khmin
↓ Lat100  AuroralE AltLat100 MLT		

Arrow indicates direction of increase of stitching variable

#### **Effects Kernels**

- Precomputed kernels convert flux-energy spectrum into linear radiation effects
- Kernels allow use of AE9/AP9 statistical machinery to compute effects at every time step or for every scenario, as needed, before computing confidence levels removes unneeded conservatism
- Kernels are "fast" to allow calculation of worst case transients by converting every spectrum to its effects
- V1.55 introduces dose vs. depth kernel derived from SHIELDOSE2
  - SHIELDOSE2 does not give accurate results for depths <0.1 mm (4 mils) AI equivalent
- What we need:
  - Dose-depth kernel for thin depths
  - Covering 2.5 nm 0.1 mm (10<sup>-4</sup> 4 mils) Al equivalent
  - Addresses plasma effects (10 eV 200 keV)
  - Also includes heavy ion effects (O<sup>+</sup>, He<sup>+</sup>)

#### Data Set Needs—Plasma

- Space Plasma Model (SPM) does not currently include MLT dependence
- What we need:
  - Reprocessed or new data sets with MLT coverage
  - Electrons, protons, He<sup>+</sup>, O<sup>+</sup>
  - 10 eV 100 keV
- AMPTE/CCE data set is an example of a desired data set
  - GTO orbit, ~5 yrs of data
  - Energy coverage 1.5 300 keV/e



#### Data Set Needs—General

- Additional data sets for all particle populations are needed for:
  - Addressing known spatial/energy regimes with limited coverage
- Planned addition of solar cycle dependence requires data sets for:
  - Informing/validating solar cycle variability
  - Informing/validating low altitude gradients
- What we need:
  - Low altitude, energy- and angle-resolved data sets
  - Long duration (11 years or more) for solar cycle variation



From Selesnick et al., JGR,

#### Conclusion

- AE9/AP9-IRENE continues to be maintained and upgraded as a comprehensive radiation environment design standard
  - Future releases will include new data sets and new features, driven by user needs
  - We seek models and data from the community to further these improvements
- Comments, questions, etc. are welcome and encouraged!
- Please send questions, feedback, requests for model or documentation, etc., to (copy all):
  - Bob Johnston, Air Force Research Laboratory, <u>AFRL.RVBXR.AE9.AP9.Org.Mbx@us.af.mil</u>
  - Paul O'Brien, The Aerospace Corporation, paul.obrien@aero.org

AE9/AP9/SPM: Radiation	Belt and Space Plasma Spec	ification Models	
AE9/AP9/SPM is a new set of models and plasma particles in pear-Farth sp	s for the fluxes of radiation belt		AE9/AP9/SPM Contents
design, mission planning, and other a specification. Denoted AE(9, AP9, and energetic Protons, and Standard Planato models are derived from 37 data sets board sensors. These data sets have of the particle fluxes along with estim both imperfect measurements and spectiments estimates can be obtained as statisticat the median and 95th percentile, for f1	insion planning, and other applications of climatological tion. Denote ARS, APB, and SPM Cenergetic Electrons, C Protons, and Standard Planam Model, respectively, the rederived from 37 data sets measured by satellite on- morsors. These data sets have been processed to create mags writche fluxes along with estimates to uncertainties from parfect measurements and space weather variability. These is can be obtained as statistical confidence intervals, e.g. iam and S9th percentile, for fluxes and derived quantities, en dualmin tomice		1. ATSAP Nome     2. Arstabed     2. Arstabed     3. Guid: Inference     4. Chergy and spatial coverage     b. Architecture     C. Data sets     d. Modes for running the     model     e. Recommended time     sampling
For a concise summary of the model features, see our Factsheet.     For one detail, see our Quick Reference pages.     For indix documentation, see Documents.     For Information on validations, comparisons to legacy models, and other	I features, see our Factsheet. rence pages. cuments. parisons to legacy models, and other review	s, see Validations and other evaluations.	g. Future version plans 4. Documents 5. Technical documentation b. Validations and evaluations and evaluations 5. Downloads 6. 459/469052M Team
The current version of the model, V	1.20.002, has been approved for publ	ic release. For instructions on downle	bading the
The AE9/AP9/SPM Team may be read	thed at ae9ap9@vdl.afrl.af.mil.		

 Current model downloads, documentation, news are available at AFRL's Virtual Distributed Laboratory: <u>https://www.vdl.afrl.af.mil/programs/ae9ap9</u>