

Air Force Research Laboratory



Recent Updates to the AE9/AP9/SPM Radiation Belt and Space Plasma Specification Model

15 July 2015

W. R. Johnston¹, T. P. O'Brien²,

S. L. Huston³, G. P. Ginet⁴, and T. B. Guild²

¹Air Force Research Laboratory,

Space Vehicles Directorate, Kirtland AFB, NM

²Aerospace Corporation

³Atmospheric and Environmental Research, Inc. ⁴MIT Lincoln Laboratory





Integrity ***** Service ***** Excellence







- Background on AE9/AP9/SPM model
- Release of V1.20 with new data and features
- New validation results
- Future version plans
- Dedicated web site for model distribution





What is AE9/AP9/SPM?

Record Research Land

- AE9/AP9/SPM specifies the natural trapped radiation environment for satellite design and mission planning
- It improves on legacy models to meet modern design community needs:
 - Uses 37 long duration, high quality data sets
 - Full energy and spatial coverage—plasma added
 - Introduces data-based uncertainties and statistics for design margins (e.g., 95th percentile)
 - Dynamic scenarios provide worst case estimates for hazards (e.g., SEEs)
 - Architecture supports routine updates, maintainability, third party applications
- Version 1.00 released in 2012
- Version 1.20 released in March 2015



Day of Mission (DoM)



AE9mc agg pctile 75

E9mc add pctile 9

Coverage and Application



- Expanded energy coverage: keV plasma to GeV protons
- Spatial coverage for all orbit regimes, including tailored coverage for high resolution in LEO
- Model AE9 AP9 SPM H⁺ Species e⁻, H⁺, He⁺, O⁺ e Energies 40 keV-100 keV- $1-40 \text{ keV} (e^{-});$ 10 MeV 2 GeV (V1.20) 1.15—164 keV (H⁺, He⁺, O⁺) $0.98 < L^* < 12.4$ Range in L $0.98 < L^*$ 2 < L_m < 10 < 12.4
- Model provided with GUI and CmdLine access
- Documentation includes recommended modes for typical use cases
 - Best practices document with more details is forthcoming





Data Sets—Temporal Coverage







Version 1.20 – Database Updates



- New data set (first new data to be added):
 - TacSat-4/CEASE proton data—captures new observations of elevated 1-10 MeV protons
 - Additional plasma data: THEMIS/ESA
- New electron templates
 - Improvements for inner zone electrons and for >3 MeV spectra
- New proton templates
 - Incorporate E/K/Φ and E/K/h_{min} profiles observed by RBSP/Relativistic Proton Spectrometer
 - Extend proton energies to 2 GeV
- Low altitude taper
 - Force fast fall-off of flux for $h_{min} < 100$ km.
 - Cleans up radial scalloping at altitudes below ~1000 km



V1.20 Feature Updates

- Feature improvements
 - More options for orbit element input and coordinates
 - Third party developers guide
 - Pitch angle tool—make internal pitch angle calculations accessible to users
 - More options for unidirectional flux queries
 - Easy extraction of adiabatic invariant coordinates
 - Improved error messages

tellite Model Plot		
Orbit Specification Type	Orbit Element Values	
Ephemeris File (Time+Pos)	Element Time: 18 Jan 2010 15:00:00 UT	
Two-Line Element File	Inclination (deg):	30.0
Mean Elements	RA of Ascend Node (deg):	0.0
Solar Elements	Argument of Perigee (deg):	0.0
Classical Elements	Eccentricity:	0.0
Geosynchronous	Mean Motion (rev/day):	12.5
State Vectors	Mean Anomaly (deg):	0.0
Orbit Propagator	1st deriv MM (rev/day²):	0.0
💿 Lokangle	2nd deriv MM (rev/day³)	0.0
SGP4	Bstar (Re ⁻¹):	0.0
Kepler Vise J2	Ephemeris Name: sat	
Input File:		Browse
Ephemeris Generation Time Range		
Start Time: 19 Jan 2010 05:00:00 UT 🔹 AutoFill		
End Time: 19 Jan 2010 07:00:00 UT 🚔		Parameters Changed
Time Step: 60 Seconds		Set











AP9 Validation in LEO





- Review by ESA showed discrepancies among AP9, AP8, and data (including Azur)
- Extensive review by team:
 - We trust data currently in AP9
 - AP9 model accurately represents these data sets
 - We also trust Azur data
 - Most likely explanation: Azur and S3-3 represent two different geophysical states
 - We expect that inclusion of Azur data will decrease AP9 fluxes and increase error bars
 - Need to explain discrepancies and natural variability





Next versions



V1.30 (~Aug 2015)	 Addresses an issue affecting AP9 V1.20 Monte Carlo runs for long missions (>3-4 years) Issue does not affect mean runs, perturbed mean runs, or short MC runs
V1.35 (~Sep 2015)	 Permits parallelization across scenarios, improving run times Useful for long mission MC runs
V1.50 (2016)	 New data: Protons: Azur, Van Allen/RPS, MagEIS & REPT Electrons: Van Allen/MagEIS & REPT, DEMETER/IDP Plasma: SCATHA/SC8, AMPTE/CCE & CHEM New features: Introduce kernel-based methods for fast dose/effects calculations Fix flux-to-fluence calculations to cover variable time steps—supports optimizing time steps for shorter run times
	 Allow selection of time period for calculation of fluence—supports different time periods for different effects



Kernel-Based Effects Calculation





Sample Day

- User provides Weibull or Bendel Parameters and desired shielding depths
- Utility computes "kernel" that transforms proton flux to SEE rate behind shielding (CSDA degraded)
- SEE rates computed from AP9 proton fluxes:
 - Instantaneous rate
 - Mission average rate
 - Worst case rate on desired timescale







Version 2.0



- Major feature changes:
 - Sample solar cycle—introduces a full solar cycle reanalysis as a flythrough option
 - New module frameworks for e.g. plasma species correlations, SPM stitching with AE9/AP9, auroral electrons, additional coordinates for MLT variation in SPM
 - AP9 improvements: solar cycle variation in LEO, east-west effect
 - Incorporate untrapped solar protons with statistics
- New data
 - Van Allen Probes/RPS, MagEIS & REPT protons and electrons
 - PAMELA protons—addresses high energy proton spectra
 - Other international data sets: possibilities include Cluster/RAPID-IIMS, ESA SREMs, CORONAS, NINA, Akebono/EXOS-D, SAC-C, Jason2
- Subsequent releases will include new data: DSX/SWx, ERG
- Int'l. collaborators aboard and new model name: IRENE: International Radiation Environment Near Earth





AE9/AP9 Website



- We have launched a dedicated web site for the AE9/AP9 project hosted by AFRL's Virtual Distributed Laboratory: https://www.vdl.afrl.af.mil/programs/ae9ap9
- The latest version of the model may be downloaded from this site after creating an account
- Summaries and model documentation are also available (no account needed)
- Future news and releases will be announced through the website









- AE9/AP9/SPM provides radiation environment specification to meet the needs of modern designers
- Release of version 1.20 this year demonstrates maintainability
- Future releases will include new data sets and new features, driven by user needs
- Model downloads, documentation, news are available at AFRL's Virtual Distributed Laboratory: https://www.vdl.afrl.af.mil/programs/ae9ap9





Thank You





