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

15 July 2015

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Outline

• 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?

• 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., 95<sup>th</sup> 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
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

<table>
<thead>
<tr>
<th>Model</th>
<th>AE9</th>
<th>AP9</th>
<th>SPM</th>
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<tbody>
<tr>
<td>Species</td>
<td>e&lt;sup&gt;-&lt;/sup&gt;</td>
<td>H&lt;sup&gt;+&lt;/sup&gt;</td>
<td>e&lt;sup&gt;-&lt;/sup&gt;, H&lt;sup&gt;+&lt;/sup&gt;, He&lt;sup&gt;+&lt;/sup&gt;, O&lt;sup&gt;+&lt;/sup&gt;</td>
</tr>
<tr>
<td>Energies</td>
<td>40 keV—10 MeV</td>
<td>100 keV—2 GeV (V1.20)</td>
<td>1—40 keV (e&lt;sup&gt;-&lt;/sup&gt;); 1.15—164 keV (H&lt;sup&gt;+&lt;/sup&gt;, He&lt;sup&gt;+&lt;/sup&gt;, O&lt;sup&gt;+&lt;/sup&gt;)</td>
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<tr>
<td>Range in L</td>
<td>0.98 &lt; L&lt;sup&gt;*&lt;/sup&gt; &lt; 12.4</td>
<td>0.98 &lt; L&lt;sup&gt;*&lt;/sup&gt; &lt; 12.4</td>
<td>2 &lt; L&lt;sub&gt;m&lt;/sub&gt; &lt; 10</td>
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- 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

- Protons
  - CRRES/PROTEL
  - SS-3/Telescope
  - ICO/Dosimeter
  - HEO-F3/Dosimeter
  - TSE-5/CEASE
  - POLAR/IPS
  - POLAR/HISTp
  - TACSAT-4/CEASE
- Electrons
  - CRRES/MEA/HEEF
  - ICO/Dosimeter
  - HEO-F3/Dos/met
  - HEO-F1/Dos/met
  - TSE-5/CEASE
  - POLAR/HISTe
  - GPS/BDD2 N518
  - GPS/BDD2 N528
  - GPS/BDD2 N533
  - LANL-GEO/SOPA L1990-095
  - LANL-GEO/SOPA L1991-095
  - LANL-GEO/SOPA L1991-095
  - SCATHA/SCB
  - SAMPEX/PET
- Plasma
  - POLAR/CAMMICE/MICS/HYDRA
  - LANL-GEO/MPA L1990-095
  - LANL-GEO/MPA L1990-095
  - LANL-GEO/MPA L1991-080
  - LANL-GEO/MPA L1994-084
  - LANL-GEO/MPA L1997A

New in V1.20

AP8 released
AE8 released

Distribution A: Approved for public release; distribution unlimited. 377ABW-2015-0532
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
AP9 V1.20 Validation—SAA

>35 MeV protons

SAA flux profiles are improved in V1.20 as compared to POES observations

Ratio of AP9 V1.20 median to POES data

>35 MeV protons, E-W SAA profile

>35 MeV protons, N-S SAA profile

East-west profile

North-south profile

POES MEPED background

electron contamination

electrons contamination

POES 15 obs. mean, 1998-2011

AP9 V1.2, mean of 40 MCs, run for 2005

AP9 V1.2, mean of 40 MCs, run for 2005

POES 15 obs. mean, 1998-2011

POES 15 obs. mean, 1998-2011
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

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

- 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
Summary

- 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