SOUTH ATLANTIC ANOMALY AND CUBESAT DESIGN CONSIDERATIONS

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Presenter
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Space Vehicles Directorate
South Atlantic Anomaly and CubeSat Design Considerations

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SPIE Paper 9604-24
South Atlantic Anomaly (SAA) & CubeSat Design Considerations

1.0 SAA Space Environment
2.0 Space Effects in the SAA
3.0 SAA Mitigation Strategies
Using a new combined set of models for the space environment determination needed for CubeSat design and mission planning

- 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>
</tr>
</thead>
<tbody>
<tr>
<td>Species</td>
<td>e⁻</td>
<td>H⁺</td>
<td>e⁻, H⁺, He⁺, O⁺</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⁻); 1.15—164 keV (H⁺, He⁺, O⁺)</td>
</tr>
<tr>
<td>Range in L</td>
<td>0.98 &lt; L* &lt; 12.4</td>
<td>0.98 &lt; L* &lt; 12.4</td>
<td>2 &lt; Lₘ &lt; 10</td>
</tr>
</tbody>
</table>
# What Type of Run

<table>
<thead>
<tr>
<th>Spec Type</th>
<th>Type of Run</th>
<th>Duration</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dose</td>
<td>Perturbed Mean</td>
<td>Several orbits or days</td>
<td>SPME+AE9, SPMH+AP9+Solar</td>
</tr>
<tr>
<td>Displacement Damage (proton fluence)</td>
<td>Perturbed Mean</td>
<td>Several orbits or days</td>
<td>AP9+Solar</td>
</tr>
<tr>
<td>Proton SEE (proton worst case)</td>
<td>Monte Carlo</td>
<td>Full Mission</td>
<td>AP9+Solar</td>
</tr>
<tr>
<td>Internal Charging (electron worst case)</td>
<td>Monte Carlo</td>
<td>Full Mission</td>
<td>AE9 (no SPME)</td>
</tr>
</tbody>
</table>

- Run 40 scenarios through either static Perturbed Mean or dynamic Monte Carlo
- Compute statistics by comparing results across scenarios (e.g., in what fraction of scenarios does the design succeed)
- Do not include plasma (SPM*) models in worst case runs
Data Sets—Temporal Coverage

- Plasma
  - THEMIS A/ESA
  - THEMIS B/ESA
  - THEMIS C/ESA
  - THEMIS D/ESA
  - THEMIS E/ESA

- Electrons
  - CRRES/PROTEL
  - S3-3/Telescope
  - ICO/Dosimeter
  - HEO-F3/Dosimeter
  - HEO-F1/Dosimeter
  - TSX-5/CEASE
  - POLAR/IPS
  - POLAR/HISTp
  - TACSAT-4/CEASE

- Protons
  - CRRES/MEA/HEEF
  - ICO/Dosimeter
  - HEO-F3/Dos/Tele
  - HEO-F1/Dos/Tele
  - TSX-5/CEASE
  - POLAR/HISTe
  - GPS/BDD2 NS18
  - GPS/BDD2 NS24
  - GPS/BDD2 NS28
  - GPS/BDD2 NS33
  - LANL-GEO/SOPA 1989-046
  - LANL-GEO/SOPA 1990-095
  - LANL-GEO/SOPA LANL-97A
  - LANL-GEO/SOPA LANL-02A
  - SCATHA/SC3
  - SAMPEX/PET

New in V1.20

AP8 released
AE8 released
SAA Proton Flux Source: Horn of the Inner Radiation Belt

- **Inner radiation belt:** protons + electrons
- **Outer radiation belt:** electrons

**Lines of constant L value:**
- 8
- 7
- 6
- 5
- 4

**South Atlantic Anomaly (SAA):** lowest altitude extent of inner radiation belt
SAA Couples Horn With a Weak Surface Magnetic Field

US/UK World Magnetic Model - Epoch 2015.0
Main Field Total Intensity (F)
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
SAA Spatial Extent: AE9/AP9/SPM Radiation Model

Spatial Extent of SAA

Omnidirectional 30MeV Integrated Mean Flux (protons/cm²/s)

0 5.0x10⁹ 1.0x10¹⁰ 1.5x10¹⁰ 2.0x10¹⁰
SAA Spatial Extent (300Km): AE9/AP9/SPM Radiation Model

Spatial Extent of SAA

Omnidirectional 30MeV Integrated Mean Flux (protons/cm²2/s)
Use Directional or Omnidirectional Fluxes?

DMSP-F18 2012 Average Background Counts

- Directional Flux for Fixed Orientation with respect to Earth
- Omnidirectional Flux for Random Orientation

Distribution A: Approved for public release; distribution unlimited. 377AW-2015-0607
SAA Drift Rate Over Time

From DMSP SSJ contamination

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Year</th>
<th>Latitude</th>
<th>Longitude</th>
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<tbody>
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<td>-45.1</td>
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<tr>
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<td>2010</td>
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<td>-50.6</td>
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<tr>
<td>F16</td>
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<tr>
<td>F16</td>
<td>2014</td>
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<td>-51.7</td>
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From AP9 V1.20 mean >30 MeV

<table>
<thead>
<tr>
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<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
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<td>2006</td>
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<td>2009</td>
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<tr>
<td>2020</td>
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<td>-53.0</td>
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</table>

location of SAA peak, 1989-2014

location of SAA peak, 1989-2020
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.