Radiation Environment Modeling for Spacecraft Design: New Model Developments

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NASA/GSFC

RADECS Workshop
28 September 2006
Athens, Greece

The Space Radiation Environment

Galactic Cosmic Rays
GeVs

Solar Protons
&
Heavier Ions
MeVs

Nikkei Science, Inc. of Japan, by K. Endo

Effects of Space Environments on Systems

- Plasma Charging
- Ionizing & Non-Ionizing Dose
- Single Event Effects
- Drag
- Surface Damage
- Impacts

- Degradation of micro-electronics
- Degradation of optical components
- Degradation of solar cells
- Data corruption
- Noise on images
- System shutdowns
- Circuit damage
- Torques
- Orbital decay
- Degradation of structural integrity
- Structural damage
- Decompression

Barth/2003


Space Radiation Environment Model Use During Space Mission Development and Operations

- **Mission Concept**
  - Observation requirements & observation vantage points
  - Development and validation of primary technologies
- **Mission Planning**
  - Mission success criteria, e.g., data acquisition time line
  - Architecture trade studies, e.g., downlink budget, recorder size
  - Risk acceptance criteria – include assessment of Space Weather forecasting capabilities
- **Design**
  - Component screening, redundancy, shielding requirements, grounding, error detection and correction methods
- **Launch & Operations**
  - Asset protection
    - Shut down systems
    - Avoid risky operations, such as, maneuvers, system reconfiguration, data download, or re-entry
  - Anomaly Resolution
    - Apply lessons learned to operations and modeling

Space Radiation Hazards for Humans
Golightly – AMS 2004

- Failure of life support systems
- Failure of space systems operational infrastructure
- The exposure received by humans from space radiation is an important occupational health risk.
  - Major concern is increased risk of cancer morbidity/mortality
  - Other possible health risks
    - Cataracts
    - Coronary disease
    - Damage to neurologic system (e.g., aging)
    - Genetic damage to offspring
  - The probability is very small of death during or immediately following a mission due to space radiation exposure


"Standard" Space Radiation Environment Models

"Standard" Space Radiation Environment Models

- Lacking a standardization process, *de facto* model standards have been adopted by the space community for space radiation environment models.
- The following models have been "generally" accepted as *de facto* standards:
  - AP-8 and AE-8 for radiation belt protons and electrons and plasma
  - JPL91 for solar protons
  - CREME86 for galactic cosmic rays and solar heavy ions

To be presented by Ray Ladbury at RADECS 2006, Athens, Greece, September 27-29, 2006.

Concerns about Standard Models

- The space system design and radiation health communities have identified three concerns related to *de facto* standard models:
  - The models are not adequate for modern applications;
  - Data that have become available since the creation of the models are not being fully exploited for modeling purposes;
  - When new models are produced, there is no authorizing organization identified to evaluate the models or their datasets for accuracy and robustness.

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Inadequacies of Current Models

- AE-8 and AP-8 models of the radiation belts
  - Very poor time resolution
  - Large uncertainties in some regions
  - Environment definitions do not exist for some energy ranges
  - Contemporary applications require descriptions for a wider range of climatological conditions, averages and worst case are insufficient
- Interplanetary models
  - Galactic cosmic ray model in CREME86 does not represent solar modulation accurately
  - JPL91 has limited energy spectrum definition in the high energy regime
  - Solar heavy ion models in CREME86 overestimate worst case fluences

Development of New Models

For additional information, please attend the RADECS 2007 Short Course Presentation by Mike Xapsos
**New Model Developments: Proton Belt Models**

*De facto* standard is AP-8

- Combined Release and Radiation Effects Satellite PROton Model (CRRESPRO)
  - Brautigam et al. sponsored by US Air Force Research Laboratory (AFRL)
- Low Altitude Trapped Radiation Model (LATRM)
  - Huston et al. sponsored by NASA
- Trapped Proton Model-1 (TPM-1)
  - Huston et al. sponsored by NASA and AFRL
- SAMPEX/PET Model (PSB97)
  - Heynderickx et al. sponsored by ESA

**Coverage of New Proton Models**

<table>
<thead>
<tr>
<th>Model Name</th>
<th># of Years of Data</th>
<th>Spatial Coverage</th>
<th>Energy Range (MeV)</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRRESPRO</td>
<td>1.2</td>
<td>1.15 &lt; L &lt; 5.5</td>
<td>1 &lt; E &lt; 100</td>
<td>CRRES</td>
</tr>
<tr>
<td>LATRM</td>
<td>17</td>
<td>&lt; 1000 km</td>
<td>16 &lt; E &lt; 80</td>
<td>TIROS/NOAA</td>
</tr>
<tr>
<td>TPM-1</td>
<td>Depends on Region</td>
<td>1.15 &lt; L &lt; 5.5</td>
<td>1 &lt; E &lt; 100</td>
<td>CRRES, TIROS/NOAA</td>
</tr>
<tr>
<td>PSB97</td>
<td>4</td>
<td>1.1 &lt; L &lt; 2.0</td>
<td>18.5 &lt; E &lt; 500</td>
<td>SAMPEX</td>
</tr>
</tbody>
</table>

- Note that combining the TPM and PSB97 models with an update of data taken with the SAMPEX/PET instrument would result in a fairly complete trapped proton model.
Comparison of TPM-1, PSB97, AP-8

New Model Developments: Electron Belt Models

- Combined Release and Radiation Effects Satellite ELEctron Model (CRRESELE)
  - Gussonhoven et al. sponsored by Air Force Research Laboratory (AFRL)
- FLUX Model for Internal Charging (FLUMIC)
  - Wrenn et al. sponsored by ESA
- Particle ONERA-LANL Environment Model (POLE)
  - Bourdari et al. sponsored by ONERA, Los Alamos National Laboratory (LANL), and NASA
Coverage of New Electron Models

<table>
<thead>
<tr>
<th>Model Name</th>
<th># of Years of Data</th>
<th>Spatial Coverage</th>
<th>Energy Range (MeV)</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRRESELE</td>
<td>1.2</td>
<td>2.5 &lt; L &lt; 6.8</td>
<td>0.5 &lt; E &lt; 6.6</td>
<td>CRRES</td>
</tr>
<tr>
<td>FLUMIC</td>
<td>11</td>
<td>Outer Zone</td>
<td>0.2 &lt; E &lt; 5.9</td>
<td>Various</td>
</tr>
<tr>
<td>POLE</td>
<td>25</td>
<td>Geostationary</td>
<td>0.03 &lt; E &lt; 6.0</td>
<td>LANL Instruments</td>
</tr>
</tbody>
</table>

- Volatile nature of the outer zone electron regions suggests that probabilistic models may be useful, but they are relatively unexplored.
- Worst case approaches are used to define severe electron environments.

Comparison of “Worst Case” POLE, CRRESELE, and FLUMIC Models with the AE-8 Model

**New Model Developments:**

**Galactic Cosmic Ray Model**

*De facto* standard is CREME86

- Galactic Cosmic Ray (GCR) Model from Moscow State University (MSU)
  - Solar variation is modeled with diffusion-convection theory of solar modulation
- Cosmic Ray Effects in MicroElectronics (CREME96)
  - CREME86 was updated with the GCR MSU Model
- NASA GCR Model from Badhwar and O'Neill
  - Similar approach to GCR MSU model with different implementation of the solar modulation theory
- New approach by Davis et al. at the California Institute of Technology (CIT)
  - Uses transport model for the GCRs through the galaxy preceding the penetration and subsequent transport in the heliosphere

New Model Developments:
Solar Proton Model

*De facto* standard is JP91 for cumulative fluence, CREME86/96 for worst case event fluence

- Solar Particle Event Fluence Model (SPE Fluence Model)
  - Nymmik et al. sponsored by Moscow State University
  - Based on power function distributions of event fluences
- Emission of Solar Proton Model (ESP)
  - Xapsos et al. sponsored by NASA
  - Based on satellite data from the 21 solar maximum years during solar cycles 20-22
  - Uses Maximum Entropy Principle to generate an optimal selection of a probability distribution, and Extreme Value theory to estimate worst case
  - Calculates cumulative and worst case solar proton fluences
- PSYCHIC
  - Xapsos et al. sponsored by NASA
  - ESP Model with satellite data set extended to cover the time period of 1966 – 2001
  - Energy range extended to over 300 MeV
  - Includes estimates for solar minimum spectra

**New Model Developments:**
**Solar Heavy Ion Model**

*De facto* standard is CREME86/96 for worst case event fluences

- **CRRES/SPACERAD** Heavy Ion Model of the Environment (CHIME) – Chenette et al. sponsored by US AFRL
  - Heavy ion abundances scaled to protons results in overestimates
- **Modeling and Analysis of Cosmic Ray Effects in Electronics (MACREE)** – Majewski at al. sponsored by Boeing
  - Heavy ion abundances scaled to alphas results in less conservative estimates
- **CREME96**
  - Uses the October 1989 event as a worst case
  - Most extensive heavy ion measurements are for C, O, and Fe, and remaining elemental fluences are determined from a combination of measurements in 1 or 2 energy bins and abundance ratios

*To be presented by Ray Ladbury at RADECS 2006, Athens Greece, September 27-29, 2006.*
**PSYCHIC Heavy Ion Model**

*Xapsos et al.*

<table>
<thead>
<tr>
<th>Model Name</th>
<th>Measurement Period</th>
<th>Energy Range (MeV/n)</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha Particles</td>
<td>1973-2001</td>
<td>1 &lt; E &lt; 200</td>
<td>IMP-8, GOES</td>
</tr>
<tr>
<td>C, N, O, Ne, Mg, Si, S, Fe</td>
<td>1997-2005</td>
<td>0.2 &lt; E &lt; 5.9</td>
<td>ACE/SIS</td>
</tr>
<tr>
<td>Less prevalent elements</td>
<td>-</td>
<td>-</td>
<td>Abundance model</td>
</tr>
</tbody>
</table>

- Model is published
- Looking for funding to develop interface

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**Model Standardization**

For additional information, please see

http://www.oma.be/ISO/

http://www.oma.be/PSRB/
**Working Group Meeting on New Standard Radiation Belt and Space Plasma Models**

- Workshop was held on 5-8 October 2004 to address concerns related to radiation belt models
- Representatives from international science, modeling, and user communities
- Three agreements were reached related to model standardization
  - Use the existing capability of the COSPAR Panel on Standard Radiation Belts (PSRB) for preparing AE-8 and AP-8 model updates for submission for ISO standards
  - Propose POLE as an update to AE-8 in the geostationary region
  - Propose to combine TPM-1 and PSB97 as an update to AP-8 in the <1000 km altitude region

**Summary**

- POLE (Particle ONERA-LANL Environment) Electron Model for geostationary orbits and the Low Altitude Proton (LAP) Model based on TPM-1/SAIC and PSB97/ESA were accepted by PSRB for standardization
- Recommend that a similar process be followed for standardization of interplanetary models
- Areas for model improvements
  - Need better definition in low energy regime for materials
  - Radiation belts
    - Need to understand source and loss mechanisms
    - Need to exploit data from new missions and newer modeling techniques
  - Galactic Cosmic Rays
    - Implement physical models of cosmic ray transport to model solar modulation
  - Solar Particle Events
    - Need to understand storage and release processes in the solar structure to gain insight into statistical characteristics

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• October Model Workshop