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Outline

• Why a new trapped model?

• A quick review of Budapest presentation (WRMISS18, Sep. 2013)

• Availability of AE9/AP9/SPM on SPENVIS
  I. Implementation on the current version SPENVIS-4 (IRENE)

• Missing databases in AE8/AP8 and different run modes of AE9/AP9

• AE9/AP9 spectral (energy) gridding for a GTO orbit

• AP9 ISS environment simulation (4 April 2014)
  I. Perturbation vs. Monte Carlo mode (advantages/disadvantages)

• AP9 model verification with CRRES Model (4 July 2011)

• AP9 validation using POES and TACSAT4 satellites measurements
  I. January 1999 (after cycle 22 solar minimum)
  II. January 2005 (after cycle 23 solar maximum)
  III. October 2011

• Summary and current/future works
Currently there are ~ 1100 satellites in orbit:

I. ~ 500 in low Earth orbit (LEO)
II. ~ 70 in medium Earth orbit (MEO), mostly US-GPS and RU-GLANOS
III. ~ 450 in geosynchronous/geostationary orbit (GEO)
IV. ~ 35 in highly elliptical orbit (HEO)

~ 80% of global financial markets rely on US-GPS satellites atomic clocks for synchronization (cesium or rubidium)*

*US GPS clock error ~ 50 nano sec./day
*RU GLANOS clock error: better than US-GPS ???
*EU-ESA Galileo (Munich/Fucino)

Global space industry revenue ~ $300 billions in 2012

I. Communication ~ $180 billions
II. TV (transmission, etc…) ~ $90 billions
III. Radio broadcast (XM, Sirius, etc…) ~ $5 billions
IV. Others ~ $25 billions
AE8/AP8 are static models (1964/1972 maps) with following limitations

I. Lacks probability distribution or error bars (i.e. no statistics)
II. Lacks sufficient spectral (energy) coverage for plasmas and energetic electrons/protons
III. Are only omni-directional
IV. Lacks sufficient spatial coverage for most orbits (MEO, GEO, GTO, HEO, …)
V. AE8/AP8 under/over predict most measurements

In order to overcome the above limitations, US developed AE9/AP9/SPM

I. SPM is Space Plasma Model with directional (anisotropy) capabilities
II. In Budapest I mentioned that AE9/AP9 (no SPM) will be licensed to SPENVIS

As of now AE9/AP9 model is not yet used for ISS daily operations

No ISS external measurements were included in developing the AE9/AP9/SPM

For the rest of the talk: AE8/AP8 will be called “old model”
AE9/AP9 will be called “new model”
Review of WRMISS18 (part II)
Availability of AE9/AP9 on ESA’s SPENVIS-4

SPENVIS Project: TEST-FFB
Radiation sources and effects
Trapped radiation: IRENE AE9/AP9 parameters

The current version of the AP9/AE9 model is provided for evaluation purpose by its development team.

Warning: due to the size of the trajectory (4142 points) the execution time could exceed your allowed quota.

Tool developed by
• AE8/AP8 has no database to provide information on the uncertainty in the mean flux maps due to measurement/gap-filling errors

• AE8/AP8 has no database to provide information on the uncertainty in the mean flux maps due to dynamic variations of space weather processes

• AE9/AP9 provides databases for both measurement/gap-filling errors and dynamic variations of space weather processes errors

• These databases allow extraction of statistical information from AE9/AP9
AE9/AP9 Runs Modes

- The AE9/AP9 model offers 4 run modes corresponding to various types of flux data:
  - **Mean**: mean behavior of the model with no uncertainty added.
  - **Percentile**: statistical behavior of the model with no uncertainty added. Uncertainty allows dynamic estimation of design margin (e.g., 99% CL) which allows study of surface or internal charging, SEU, and evaluation of satellite lifetime.
  - **Perturbed Mean (PM)**: adds the uncertainty in the mean flux maps due to measurement and gap-filling errors.
  - **Monte Carlo (MC)**: contains all of the PM uncertainty plus an estimate of the dynamic variations due to space weather processes.

*PM and MC selections require ‘number of scenarios (runs)’. I will show results for 10 scenarios later.*
Energy Bins Differences (part I)

Default IRENE grid

<table>
<thead>
<tr>
<th>Proton Energies (MeV)</th>
<th>0.1, 0.2, 0.4, 0.6, 0.8, 1, 2, 4, 6, 8, 10, 15, 20, 30, 50, 60, 80, 100, 150, 200, 250</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron Energies (MeV)</td>
<td>0.04, 0.07, 0.1, 0.25, 0.5, 0.75, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8</td>
</tr>
</tbody>
</table>

Latest version (1.2)

<table>
<thead>
<tr>
<th>Proton Energies (MeV)</th>
<th>0.1, 0.2, 0.4, 0.6, 0.8, 1, 2, 4, 6, 8, 10, 15, 20, 30, 50, 60, 80, 100, 150, 200, 300, 400, 700, 1200, 2000</th>
</tr>
</thead>
</table>

Energy Bins Differences (part II)

Aluminum 1016 g/cm²
Water 805.4 g/cm²
Energy Bins Differences (part II)

(GTO orbit)
Energy Bins Differences (part III)

US-GPS (20200 km)
RU-GLONASS (19100 km)
PM Mode (10) AP9 ISS Spectra (4 April 2014)
MC Mode (10) AP9 ISS Spectra (4 April 2014)
ISS, PM/MC Modes Comparison (4 April 2014)

PM mode (10)

MC mode (10)
### CRRES: Combined Radiation and Release Experiment Satellites

<table>
<thead>
<tr>
<th>Satellite/Sensor</th>
<th>Orbit</th>
<th>Energy range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protons</td>
<td>CRRES/PROTEL: 50 km × 33000 km, 18°</td>
<td>(MeV) 2.0 - 80</td>
</tr>
</tbody>
</table>

All **AP9** scenarios ran for **1 week** mission time
All **AP9** scenarios used **10 Monte Carlo** runs
For **AP9** only aggregated mean, median and 95%CL values are included
For **AP8** only **mean** values are available
AP9 Model Verification with Other Models (part II)

AP8/AP9/CRRESPRO differential flux/fluence comparisons
LEO-ISS, 400 km X 51.6 deg., circular, epoch 04-Jul-2011

2 MeV

Flux, #/(MeV·cm⁻²·s)

Day of mission, DoM

80 MeV

Flux, #/(MeV·cm⁻²·s)

Day of mission, DoM

Fluence, #/(MeV·cm⁻²)

Day of mission, DoM

AP9 Validation set, Ver. 1.05
AP9 Model Verification with Other Models (part III)

AP8/AP9/CRRESPRO differential fluence comparison
LEO-ISS, 400 km X 51.6 deg., circular, epoch 04-Jul-2011

Fluence, #/(MeV·cm²·yr) at DoM=7

- CRRESPRO_active
- AP9_mean
- AP9_median
- AP9_95%CL
- AP8max

E, MeV
### AP9 Validation

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Sensor</th>
<th>Orbit</th>
<th>Time Period</th>
<th>Energies (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>POES</td>
<td>SEM2 MEPED</td>
<td>LEO 850 km, circular, 98.7°</td>
<td>Jul 1998 – Dec 2011</td>
<td>&gt;16, &gt;36, &gt;70, &gt;140</td>
</tr>
<tr>
<td>TACSAT4</td>
<td>CEASE</td>
<td>MEO 735 km x 12024 km, 63.5°</td>
<td>Oct 2011 Dec 2012</td>
<td>&gt;16, &gt;29, &gt;39, &gt;44, &gt;72</td>
</tr>
</tbody>
</table>

**POES Validation epochs:**
- Jan. 1999 (after cycle 22 solarmin)
- Jan. 2005 (after cycle 23 solarmax)

**TACSAT4 Validation epoch:**
- Oct. 2011

✗: Excluded due to electron contamination
January 1999/2005 AP9 Validation, POES (part III)

- **1999 0.3 day**
  - Integral Flux, #/cm²s²
  - Day of Simulation: 4.7 to 5

- **1999 5 days**
  - Integral Flux, #/cm²s²
  - Day of Simulation: 0 to 5

- **2005 0.3 day**
  - Integral Flux, #/cm²s²
  - Day of Simulation: 4.7 to 5

- **2005 5 days**
  - Integral Flux, #/cm²s²
  - Day of Simulation: 0 to 5

> 70 MeV

AP9 Validation set, Ver. 1.05
January 1999/2005 AP9 Validation, POES (part IV)

> 140 MeV

1999 0.3 day

1999 5 days

2005 0.3 day

2005 5 days

Integral Fluence, #/cm^2 s

Day of Simulation

> 140 MeV

Integral Flux, #/cm^2 s

Day of Simulation

Integral Fluence, #/cm^2 s

Day of Simulation

Integral Flux, #/cm^2 s

Day of Simulation

AP9 Validation set, Ver. 1.05
October 2011 AP9 Validation, TACSAT4 (part V)

**T09 > 43.7 MeV**

- **2011 0.3 day**
- **2011 80 days**

**T08 > 71.9 MeV**

- **2011 0.3 day**
- **2011 80 days**

Flux, #/cm² s

Fluence, #/cm²
## AP9 (PM/MC) Run Times

<table>
<thead>
<tr>
<th>Transit Trajectory - Crew1out to 50,000 km</th>
<th>Perturbed Mean</th>
<th>Monte Carlo</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.763</td>
<td>2.005</td>
</tr>
<tr>
<td>50</td>
<td>4.532</td>
<td>5.585</td>
</tr>
<tr>
<td>100</td>
<td>7.77</td>
<td>10.063</td>
</tr>
<tr>
<td>250</td>
<td>17.652</td>
<td>23.28</td>
</tr>
<tr>
<td>500</td>
<td>35.757</td>
<td>47.814</td>
</tr>
<tr>
<td>999</td>
<td>66.618</td>
<td>89.445</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1 Day - ISS Orbit</th>
<th>Perturbed Mean</th>
<th>Monte Carlo</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>16.092</td>
<td>17.269</td>
</tr>
<tr>
<td>50</td>
<td>41.857</td>
<td>45.414</td>
</tr>
<tr>
<td>100</td>
<td>73.495</td>
<td>80.682</td>
</tr>
<tr>
<td>250</td>
<td>168.289</td>
<td>186.369</td>
</tr>
<tr>
<td>500</td>
<td>327.021</td>
<td>362.435</td>
</tr>
<tr>
<td>999</td>
<td>643.048</td>
<td>714.52</td>
</tr>
</tbody>
</table>
Using IRENE (SPENVIS) version of AE9/AP/SPM, I discussed:
I. Deficiencies of AE8/AP8 model
II. Plans for implementing AE9/AP9 model on SPENVIS-4 and SPENVIS-NG
III. Statistical capabilities of AP9 model in PM and MC modes
IV. For ISS, verification among AP8, AP9 and CRRES-proton models
V. Validation of AP9 model using POES and TACSAT4 satellites measurements

Current version (1.20, July 2014) not available on SPENVIS yet
I. Updated flux maps for electrons/protons
II. Partial inclusion of data from Van Allen twin satellites to:
   I. Study GeV protons using relativistic proton spectrometer (RPS) measurements
   II. Separate temporal/spatial anomalies

On going work to release Version 2 of AE9/AP9/SPM (2015 ??)