# Radiation and Plasma Effects Working Group

Decided to focus on space weather models, impact:

Not bothered about GCR codes or trapped proton codes (except maybe for comparison purposes).

Space weather effects include:

- Surface charging (J. Minow, N. Ganushkina, D. Pitchford)
- Internal Charging (P. O'Brien, Y. Shprits)
- SEEs (M. Xapsos, P. Jiggens, J. Mazur)
- Radiation at aviation altitudes (K. Tobiska, M. Meier)
- Total Dose in solar array and electronics due to SPEs and electron enhancements (I. Jun, M. Xapsos, T. Guild)
  - >100 keV electrons
  - >1 MeV protons

# Summary of Metrics

1. Fix Orbits: polar LEO, MEO, GEO, GTO, polar aircraft route
2. Derive effects metrics based on standard orbits/components.

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|---|---|---|---|
| **Surface charging** | 12 keV e- flux | 12 keV e- flux; $T_e$; $N_e$ | seconds |
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| **SEEs** | SEE rate [100 mils] | >30 MeV p+ flux; >15 MeV.cm$^2$.mg$^{-1}$ LET flux | 5-min, daily, weekly |
| **TID** | Dose in Si [100 mils; 4 mils] | 30-50 MeV p+ flux;<br>>1.5 MeV e- flux<br>1-10 MeV p+ | Daily, weekly |
| **Aviation** | Dose rate in aircraft (D-index) | 2 spectral parameters (power law with rigidity) | 5-min, Hourly |

Above is draft minimal set

*P. Jiggens et al.*

# Surface Charging Status

- Initial effort will focus on high priority GEO, MEO, GTO, and LEO polar environments where surface charging can exceed hundreds of volts

- User groups include spacecraft designers, operational situational awareness, anomaly investigations, and impact on science measurements

- Metrics (team is evaluating options):
  - Statistical evaluation using O'Brien "green anomalies" technique
  - Parameters used for inputs to charging models
    - GEO, MEO, GTO: Ne, Te, Ni, Ti or other
    - LEO polar (auroral): Ne, $E_{beam}$, $\Delta E_{beam}$, and other Fontheim parameters
    - Flux spectra at different locations

- Environment models (initial focus):
  - Ovation – CCMC implementation
  - LANL model (Vania Jordanova)
  - IMPTAM (Natalia Ganjushkina) ), run online in near-real time since 2013
  - CIMI (Natalia Buzulukova)

- Spacecraft charging models (secondary effort, but compare with $\Phi_{s/c}$)
  - Nascap
  - SPIS
  - SPENVIS, MUSCAT, and other small group charging codes

*J. Minow, N. Ganushkina*

# Internal Charging Summary

Internal charging headline metrics:

- User Metrics: % Green anomalies for 24-hour average current beneath 100 mils Al spherical: GEO, GTO
- Science Quantity (stat TBD): Omnidirectional differential or integral flux: GEO, GTO

Internal charging events/intervals

- 2015 has some nice big storms, RBSP data to validate
- The March, April, June, and July 2015 storms (TBR: need CME and CIR/HSS storms)

Internal charging "comprehensive" metrics:

- User Metrics Add: 6-, 72-hour averages; 40, 350 mils; LEO, HEO, GNSS
- Science Quantities Add: locally mirroring flux; 0.1-1 MeV; LEO, HEO, GNSS

Models (**Bold** indicates high probability of running benchmarks soon):

- **VERB, RBE/CRCM/CIMI, DREAM**, BAS, Rice REM, Salammbo
- CRRESELE in Ap mode
- **GREEP, SWPC REFM**, Ukhorskiy nearest neighbors, NARMAX

*P. O'Brien, Y. Shprits*

# Internal Charging Areas of Concern

- We are not currently addressing how the metrics account for model error: is it really a "green" anomaly if the model error bar included some yellow?
- We are not addressing mission design specs (Satellite design users, govt agency, insurers): out of scope, and hard to validate a 95% confidence value for 10-year worst case without 200 years of data.
- How do we address designer, insurer, govt agency needs? By including most severe, well-observed events in our validation set.
- We are concerned about the comparability of models with different inputs (observed initial/boundary conditions, versus initial/boundary conditions provided by a coupled model)

*P. O'Brien, Y. Shprits*

# Total ionizing dose – Preambles

- Total dose is a climatological quantity, not space weather quantity
  – For mission duration
  – In order of days or years
- Total dose estimate for a mission uses a long-term average environment, not the worst case environment
- Quantities that are need to compute total dose
  – Trapped electron and proton fluence spectra for a given mission duration
  – SEP mission fluence spectrum
- Empirical (climatological) models are typically used for total dose calculation for a mission
  – e.g., AP9/AE9 for trapped particles or JPL/ESP for solar protons

*Insoo Jun, Mike Xapsos*

(1) Identify user groups
  - Satellite designer (SD) for both commercial and government
  - Satellite operators and anomaly analysts (SOAA) for both commercial and government
  - Scientists (SCI) for both academia and government

(3) Identify metrics for each user group
  - SD: Dose-depth for the mission
  - SOAA: Dose-depth from launch to given time (there are some data available)
  - SCI: proton and electron energy spectra
    - Electrons for > 100 keV
    - Protons for > 1 MeV

(5) Identify empirical models for each metric
  - Trapped: AE8/AP8; AE9/AP9/SPM; IGE2006/POLE (other older models are also available (e.g., CRESSELE, CRESSPRO, etc.))
  - Solar: King (1972); JPL; ESP/PSYCHIC; SAPPHIRE

(7) Identify physical model for each metric
  - Trapped: SALAMMBO; DREAM
  - Solar: SOLPENCO

*Insoo Jun, Mike Xapsos*

# Future Need

- Climatological models
- Flight data to continuously improve and update the existing empirical models
  - Flux energy spectra
  - Dosimeter data

*Insoo Jun, Mike Xapsos*

# SEEs: Summary

- Trapped protons
  - AP9 (also AP8 still used in some standards);
  - PSB97 + update (local model based on SAMPEX/PET)
- SEPs
  - ESP-PSYCHIC
  - JPL
  - MSU
  - SAPPHIRE
- GCRs
  - ISO-15390 GCR model
  - Badhwar-O'Neill (BON)
  - DLR GCR model
- Magnetospheric Modelling codes:
  - ESHIEM-MSM (magnetospheric shielding code)
  - Shea and Smart model

Relevant parameters

a) SD+SLAO (SEU rate): proton fluxes (>30 MeV & > 50 MeV) [radiation belt peak vales (5-minute); worst-case SEP values; worst-case solar particle event (SPE) fluence]

b) SD (SEL/SEB probability): proton fluences (>30 MeV & > 50 MeV) [Orbit-averaged radiation belt flux (fluence); cumulative SEP fluence]

c) SD+SLAO+SO: Abundance ratios and charge states of SEP heavy ions (Z>2) [extension to event-to-event variability/distributions if possible]

d) SD+SLAO: LET behind nominal shielding** (1 $g.cm^{-2}$)

***application of particle transport codes as black box only to derive useful quantities*

Validation methods

a). Statistical evaluation using O'Brien "green anomalies" technique

b. Event /interval based

*P. Jiggens, M. Xapsos, J. Mazur*

# Summary: Radiation Effects for Aviation

1. data: compare absorbed dose rate in silicon or ambient dose rate equivalent, depending on instrument characteristics
2. models: compare effective dose rate
3. RMS metrics for error
4. use version numbers for data and models
5. need more data (spectral and TID) for model comparison/ validation
6. report time (UT), lat, lon, dose rate for ease of comparison
7. support development of D-index for aviation community and discourage use of NOAA S-scale for aviation radiation

*K. Tobiska, M. Meier*

# Statistics for Flux-based Metrics

- Want a metric that treats 2x error same as 0.5x error, does not explode when flux is zero
- Working w/ Steve Morley to define metrics based on Median Symmetric Accuracy with support
- MSA = 100% x Median of {|Big - Small|/Small}
- *Big* is the larger of flux or observation, *Small* is the smaller one
- Support means determining a *floor* on the observations below which all observed or modeled values are replaced by the *floor* itself.
  - Avoids zeros in denominator.
  - Does not penalize model for estimating fluxes well below the 1 count level of a flux sensor.
- In addition to MSA, we will include metrics that separate error *bias* from error *spread*
- (Bias can sometimes be attributed to the instrument, not the model, so we want to break it out)

*P. O'Brien*

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