International Forum for Space Weather Capabilities Assessment

Focus: Radiation and Plasma Effects Working Team's progress

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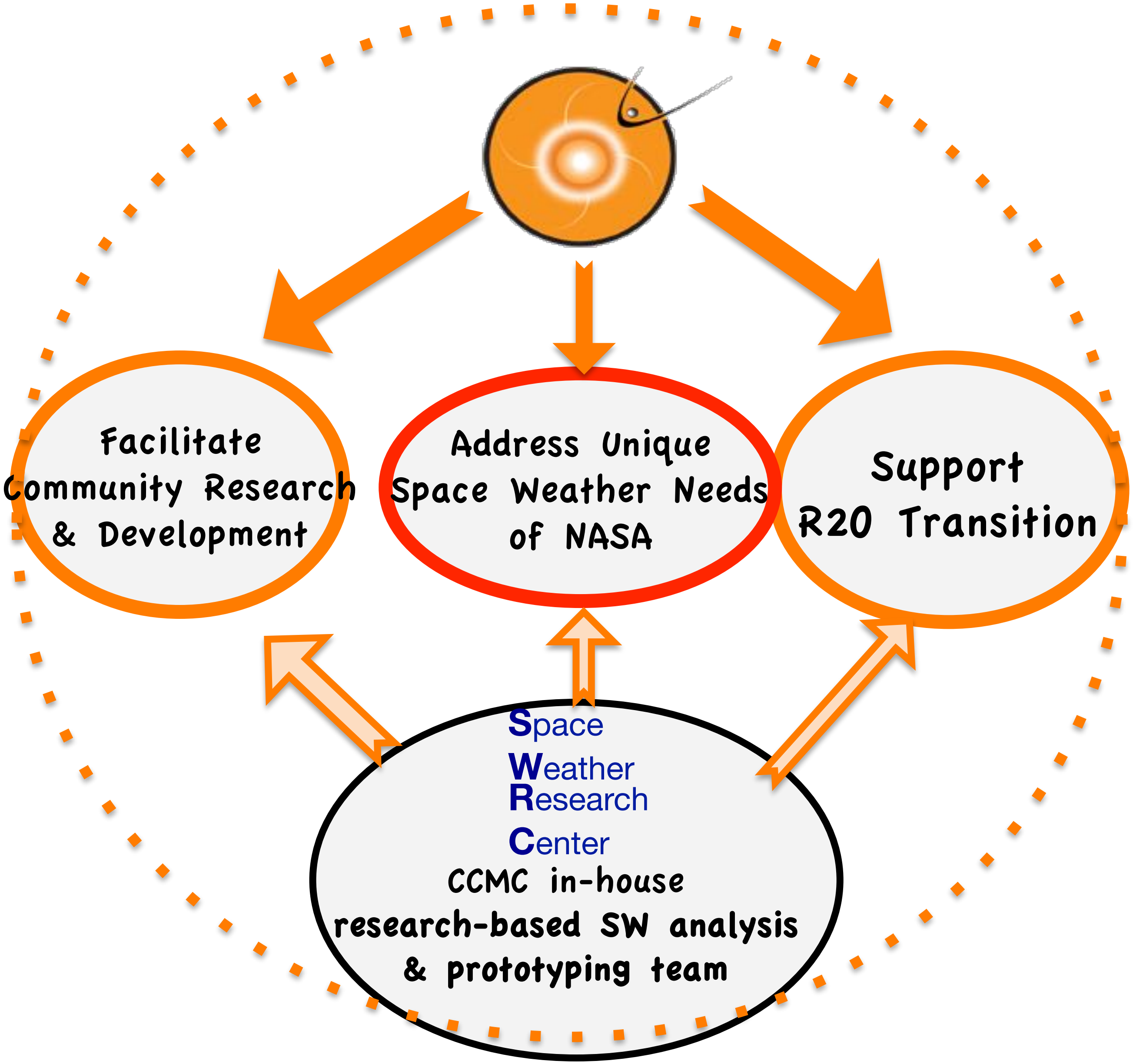
Space Environment Engineering and Science Applications Workshop

8 September 2017

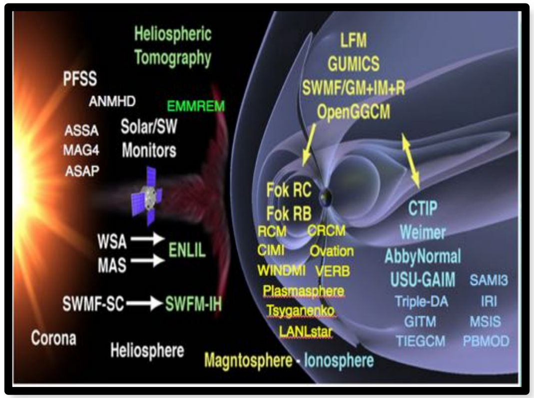
CCMC

The Community Coordinated Center



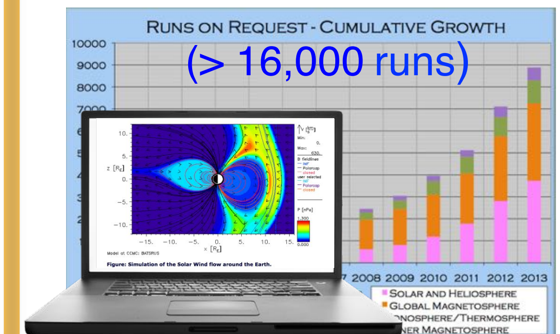
CCMC Assets & Services

Models

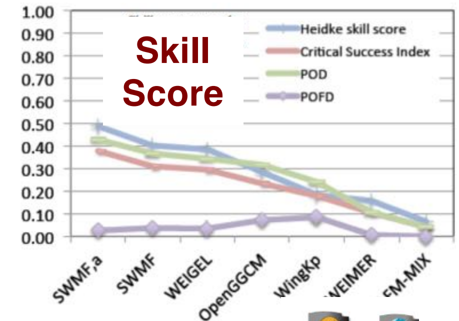


(expanding collection: > 80)

Simulation Services



Assessment



Scoreboard

Dissemination

Flexible Infrastructure

Tools, Databases

Actionable Displays

iSWA: solar, heliosphere, magnetosphere, ionosphere, planetary

KAMELEON

CONVERSION • ACCESS • INTERPOLATION

Space Weather Services

for NASA's missions

Space Weather Research Center

Hands-on

Education

International Forum on Space Weather Capabilities Assessment

The Forum brings together space environment experts, models developers, data providers, forecasters and end-users to

- define **internationally recognized metrics** that are meaningful and informative to end-users, developers, and decision makers;
- evaluate the **current state** of space environment models, applications and forecasting techniques;
- establish a procedure to **quantify and track progress** over time;
- facilitate **communications** between forecasters and researchers;
- **address challenges** in data-model comparison

https://ccmc.gsfc.nasa.gov/assessment/.

SUPERTOPIC: QUANTIFYING SCIENTIFIC PROGRESS

- Assessment of Understanding and Quantifying Progress Toward Science Understanding and Operational Readiness

SOLAR

- Solar Flare Prediction Coronal & Solar Wind Structure
- 3D CME kinematics and topology
- Solar Indices and Irradiance

GEOSPACE: Geomagnetic Environment

- Ground Magnetic Perturbations: dBdt, delta-B, GICs, FACs
- Geomagnetic Indices
- Magnetopause location and geosync. orbit crossing

HELIOSPHERE

- CME Arrival Time
- IMF Bz at L1
- SEPs

GEOSPACE: Auroral Region

- Auroral precipitation and high latitude ionosphere electrodynamics

RADIATION and PLASMA EFFECTS

- Surface Charging
- Internal Charging
- Single Event Effects
- Total Ionizing Dose
- Radiation effects for aviation

IONOSPHERE

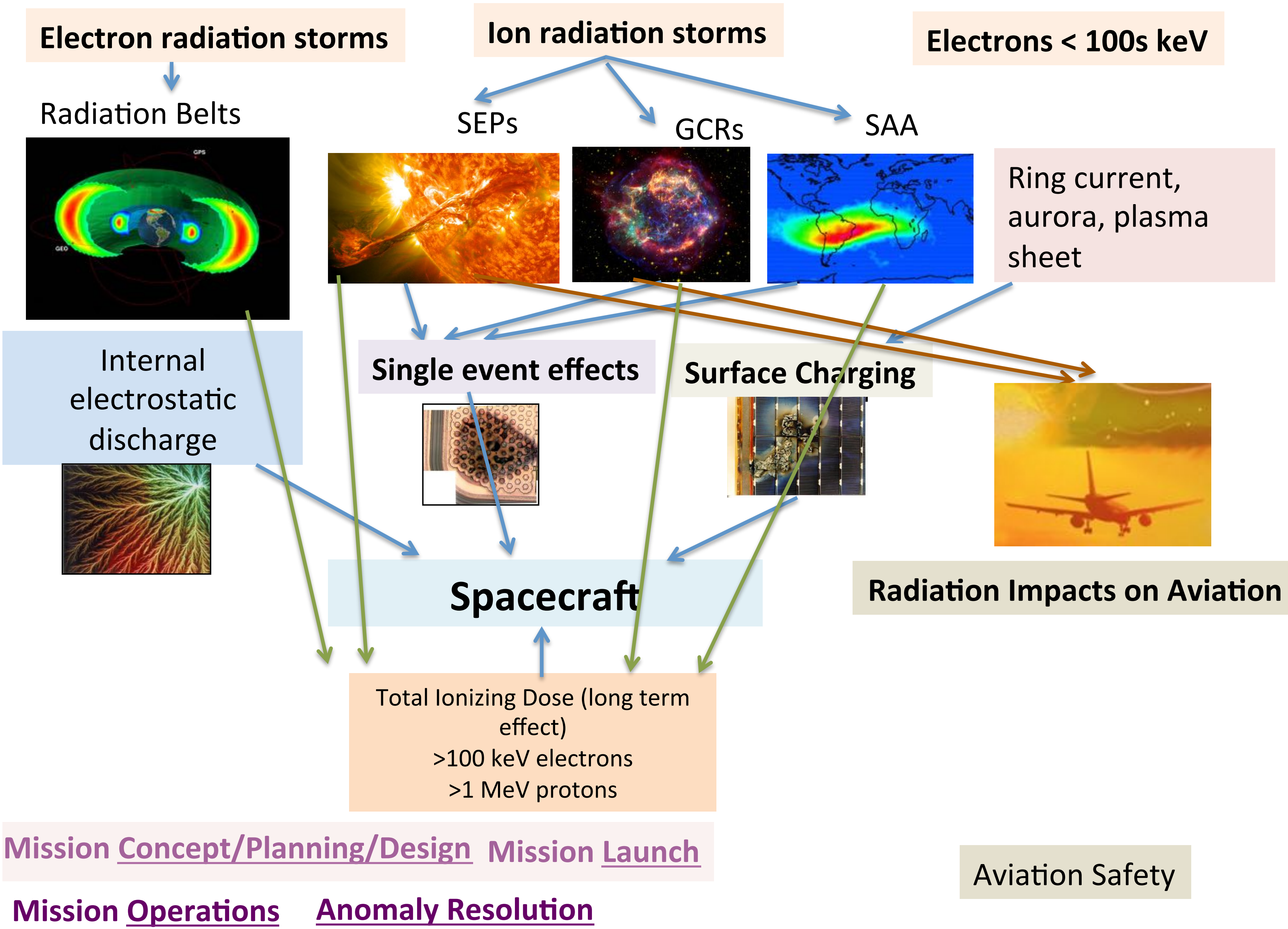
- Neutral Density and Orbit Determination at LEO
- Global & Regional TEC
- Ionosphere Plasma Density: NmF2/foF2, hmF2, TEC
- Ionosphere Scintillation

INFORMATION ARCHITECTURE

- Information Architecture for Interactive Archives (IAIA)

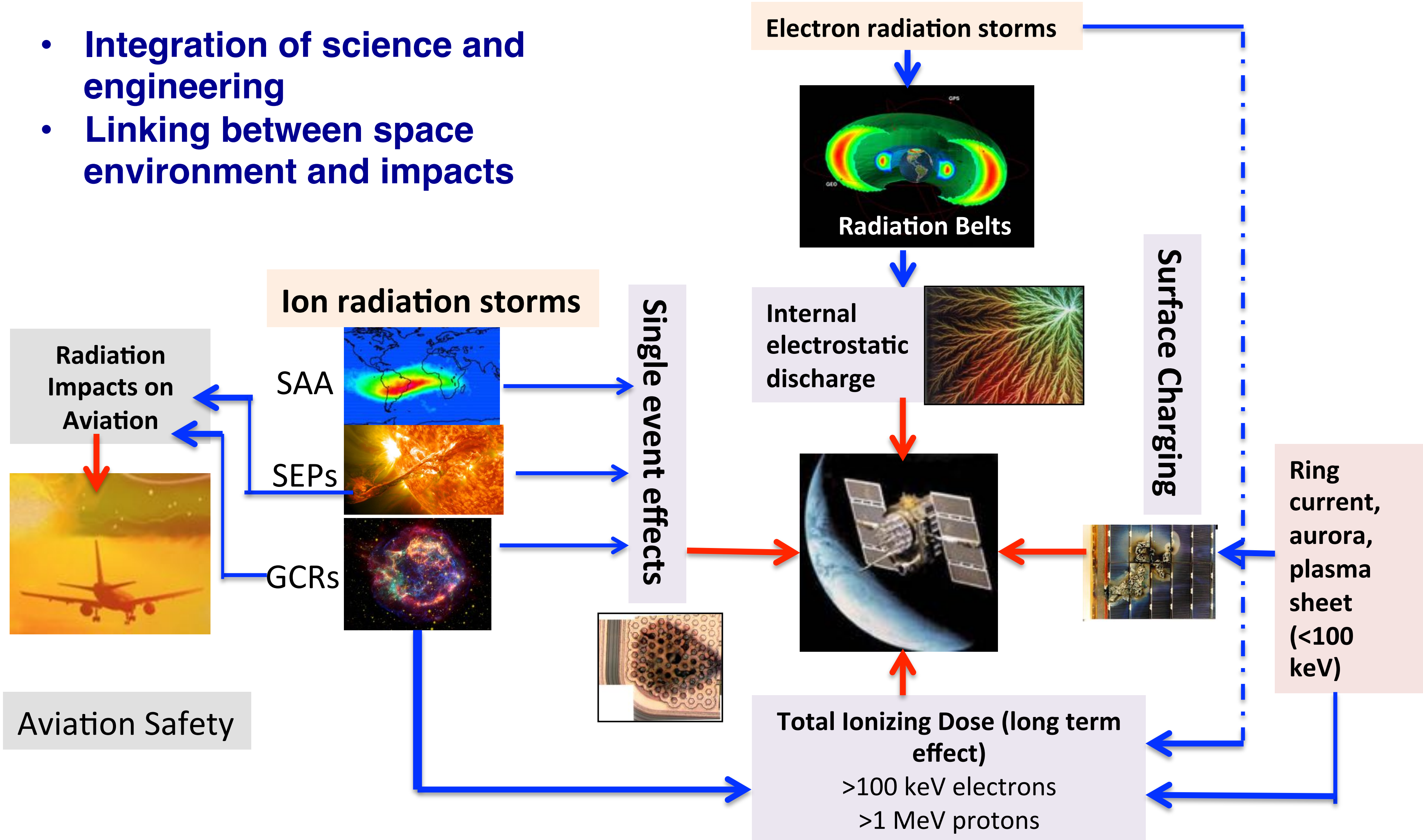
The Radiation & Plasma Effects Working Team

- **Radiation and Plasma Effects Working Team deals with five different subtopics with a variety of plasma & particle populations**
- **It bridges the space environments, engineering and user community**. Close collaboration among them becomes even more paramount. **Choosing proper metrics** that are simple yet meaningful to different groups of people, and measurable over a long period of time, is a challenge.
- International Forum for Space Weather Capabilities Assessment intends to be a long-term, community wide effort. Focus of this presentation: what has been achieved at the first workshop (April 3-7, 2017, Cape Canaveral, FL) arising from the forum.



Electron radiation storms
Radiation Belts
Ion radiation storms
SEPs
GCRs
SAA
Electrons < 100s keV
Ring current, aurora, plasma sheet
Internal electrostatic discharge
Single event effects
Surface Charging
Spacecraft
Radiation Impacts on Aviation
Total Ionizing Dose (long term effect)
>100 keV electrons
>1 MeV protons
Mission Concept/Planning/Design
Mission Launch
Mission Operations
Anomaly Resolution
Aviation Safety

- **Integration of science and engineering**
- **Linking between space environment and impacts**



Mission Concept/Planning/Design   Mission Launch

Mission Operations   Anomaly Resolution

Radiation and Plasma Effects Working Group co-leads

Decided to focus on **space weather models**

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)

Summary of Metrics

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

	Effect Metric	Science Predictands	Time Period (Space Weather)
Surface charging	12 keV e- flux	12 keV e- flux; T_e; N_e	seconds
Internal charging	>100 fA/cm^2 [100 mils]	1 MeV and >2 MeV e- flux	24-hour averaged
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; >1.5 MeV e- flux 1-10 MeV p+	Daily, weekly
Aviation	Dose rate in aircraft (D-index)	2 spectral parameters (power law with rigidity)	5-min, Hourly

More can be added

Stoplight Metrics

Paul O'Brien

- Satellite operators tend to prefer RED/YELLOW/GREEN stoplight indicators to real-valued quantities
- Statistical approach (over a long time interval)
- GREEN is the 75th percentile and below, RED is the 97th percentile and above.
- This fixes the proportion of GREEN/YELLOW/RED in time: 75% GREEN, 22% YELLOW, 3% RED
- If anomalies are rare, then the false YELLOW rate is 22% and the false RED rate is 3%
- A good metric, then, is what percent of *anomalies* occur when the tool is outputting GREEN?
- A unifying metrics for surface charging, internal charging, single event effects, total dose

Surface Charging Status

- 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}, ΔE_{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

- 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 needed 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

(2) 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

(3) 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

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

Insoo Jun, Mike Xapsos

Future Need (TID)

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

Insoo Jun, Mike Xapsos

SEEs: Summary (1/2)

- 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 (rigidity cutoff calculation):
  - ESHIEM-MSM (magnetospheric shielding code)
  - Shea and Smart model

P. Jiggens, M. Xapsos, J. Mazur

SEEs: Summary (2/2)

Relevant parameters

a) SD+SLAO (SEE rate): proton fluxes (>30 MeV & > 50 MeV) 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*

- SD: Satellite designer
- SLAO: Satellite/launcher/aircraft operators
- SO: Standards organizations (ISO/ECSS/NASA internal)

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 (Root-Mean-Square) 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, altitude, 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

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Outlook

- We have made headway at the April 2017 workshop.
- Will continue to make progress via telecons or other science meetings (GEM, CEDAR, SHINE, AGU….)
  - Will have a topical discussion at the November 2017 European Space Weather Week 'How to assess space environment models' capability in satellite impact analysis'
- **Everyone is invited to participate**