Metrics for Addressing Satellite Operator Needs

Paul O’Brien
Space Sciences Department
Physical Sciences Laboratories

International CCMC-LWS Working Meeting

Overview

- What kind of user is the satellite operator?
- Radiation and plasma hazards to satellites
- Quantities (potentially) useful for satellite operations
- User metrics
- How much error is acceptable (to users)?
- Science metric

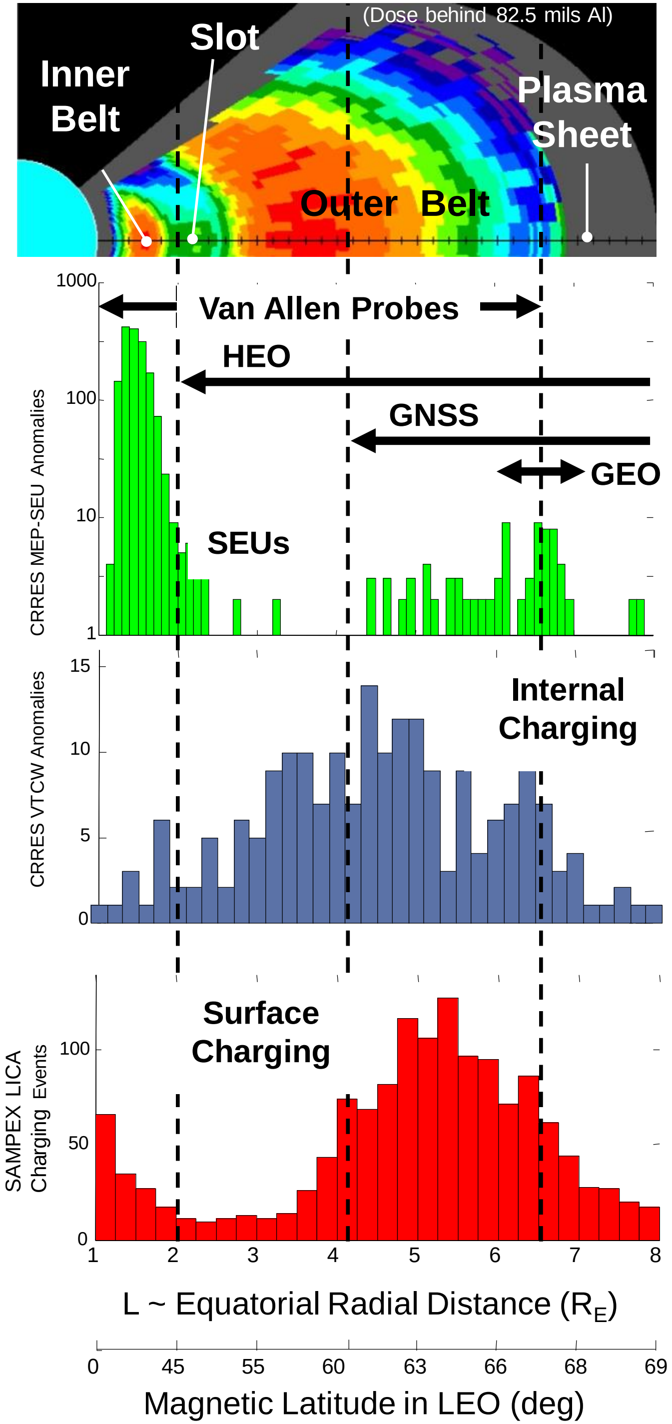
Understanding the Satellite Operator as a User

- This briefing mainly considers the satellite operator's perspective
- The satellite operator has a dozen distractions, no time, and only limited background in space weather
- The operator's priorities are typically vehicle safety first, then return to service
- Because anomalies are much rarer than hazardous environments, a space weather forecast is rarely used to modify operations. Exception: a forecast might lead to rescheduling a vulnerable operation (deploy, maneuver, etc.)

- Anomaly analysts and space weather forecasters are typically more interested in details and have more background in space weather

Paul.Obrien@aero.org
PSL/SSAL/SSD

Operational Space Environment Hazards

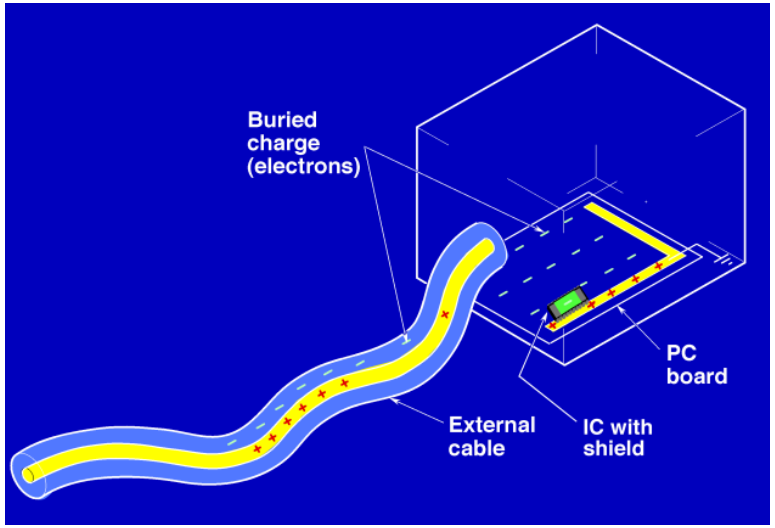


- **Event Total Dose (ETD)** occurs primarily in orbits that rarely see trapped protons in the 1-20 MeV range (e.g., GEO, GPS) because these are the orbits for which solar particle events and transient belts make up a majority of the proton dose (including displacement damage).
- **Single Event Effects (SEE)** tend to occur in the inner (proton) belt and at higher L shells when a solar particle event is in progress.
- **Internal charging (IC)** and resulting electrostatic discharges (ESD) occur over a broad range of L values corresponding to the outer belt, where penetrating electron fluxes are high.
- **Surface charging (SC)** and resulting ESD occur when the spacecraft or surface potential is elevated: at 2000-0800 local time in the plasma sheet and in regions of intense field-aligned currents. It has also been observed, but not explained, at very low L.

AEROSPACE

Effects of Space Environment

Internal Charging

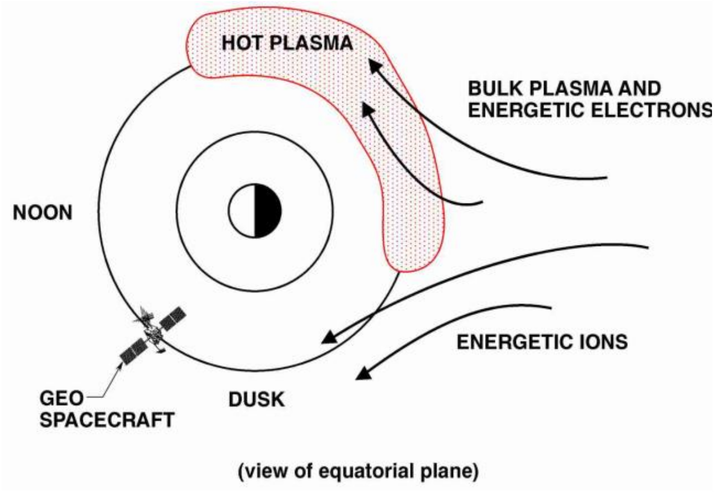


- Radiation belt electrons deposit charge on dielectrics inside spacecraft
- Electrostatic discharges occur within cables, circuit boards, and thermal blankets

Watch for enhanced energetic electrons

300 keV - 2 MeV

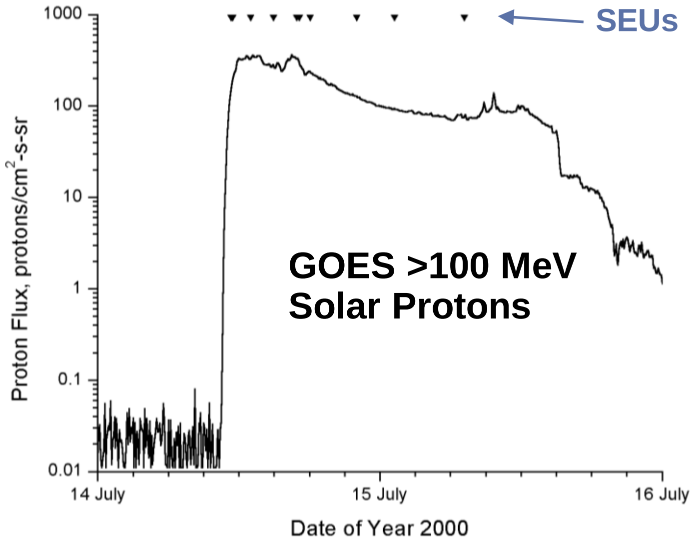
Surface Charging



- Plasma causes surface charging, especially between 2000-0800 local time and in auroral arcs
- A discharge (ESD) can introduce spikes of tens of volts in command and power lines

Watch for substorms (high magnetic index K_p) and local time, or field-aligned currents

Single-Event Effects



- Galactic Cosmic Rays, Solar Proton Events, and transient radiation belts
- Energetic protons and heavy ions deposit charge inside integrated circuits
- Electronics can latch up or burn out

Watch for enhanced solar proton flux

Paul.Obrien@aero.org
PSL/SSAL/SSD

AEROSPACE

Quantities (potentially) useful for satellite operations

- FAC intensity (LEO) [Surface Charging]
- AE Index (LEO) [Surface Charging]
- Kp [Surface Charging]
- Electron plasma temperature [Surface Charging]
- 0.1-40 keV electron flux [Surface Charging]
- 0.1-2 MeV electron flux [Internal Charging]
- 20-100 MeV proton flux (heavy ions would be nice, too) [SEE]
- 1-20 MeV proton flux [Event Total Dose]

*These quantities are used in SEAES, the Spacecraft Environmental Anomalies Expert System that relates environmental conditions to anomaly probabilities using historical relationships between the observed environment and observed anomalies. It is used for situational awareness and anomaly resolution.

User Metrics

- Metrics will need to be broken out by major orbit regimes: GEO, GNSS, PEO, HEO
- User metrics should be based on quantities the users can understand and geared toward effects:
  - *Internal current or dose rate rather than electron flux*
  - *SEE is tricky: LET spectrum for ions, but protons probably remain as flux*
  - *For IC, SEE, ETD, specify depth of shielding rather than energy*
  - *SEE and SC on “instantaneous” timescales, ETD and IC hours or days averages (along orbit)*
- User metrics might be based on success at specifying red/yellow/green state rather than error (next slide)

Paul.Obrien@aero.org
PSL/SSAL/SSD

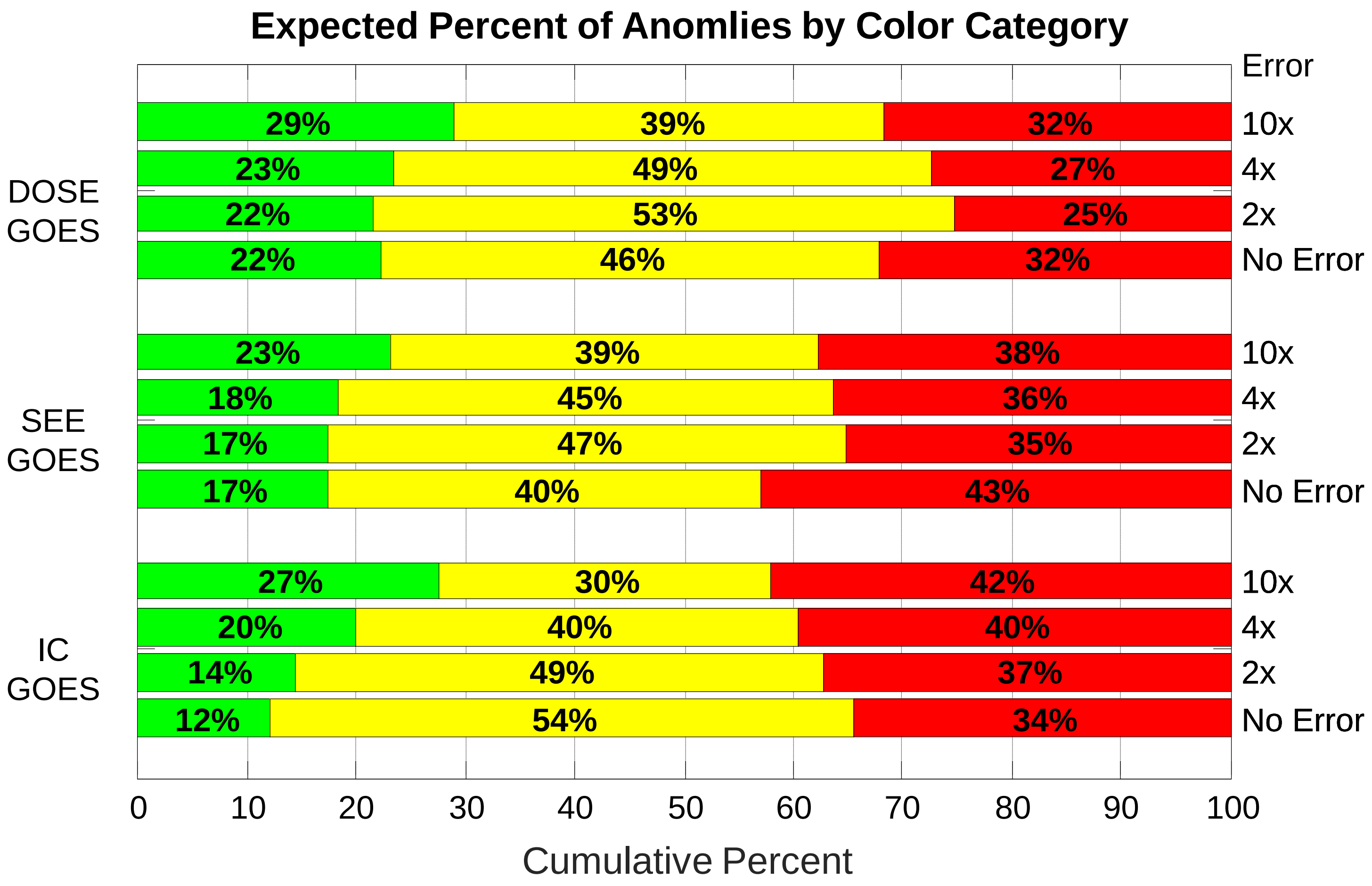
AEROSPACE

Stoplight Metrics

- Satellite operators tend to prefer RED/YELLOW/GREEN stoplight indicators to real-valued quantities
- False alarm and failure to detect rates are related to the alert threshold
- In SEAES, by default GREEN is the 75th percentile and below, RED is the 97th percentile and above. (For SEE these percentiles are computed from SEP times only)
- 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?

How much error is acceptable?

- For most anomaly types, ~20% of anomalies will occur under genuine green conditions because the probability is low, but the duration is high
- We have found that having a multiplicative error as large as a factor of 4 does not necessarily degrade performance relative to this ~20% floor
- SC does not follow this pattern



Paul.Obrien@aero.org
PSL/SSAL/SSD

Science Metrics

- Initial science metrics should be in terms familiar to the scientists and geared toward what can be observed or computed consistently
  - *Flux at a given energy and location is more straightforward than PSD versus adiabatic invariants*
  - *Flux at locations where we have regular observations*
- As the science gets more advanced, we can use metrics that are more sensitive to overall success at representing the dynamics
  - *Regional belt indices / total belt content*
  - *Radial distance of median total pressure surface*
  - *L* of median particle at fixed M,K*
  - *Principal component amplitudes*

Paul.Obrien@aero.org
PSL/SSAL/SSD

AEROSPACE