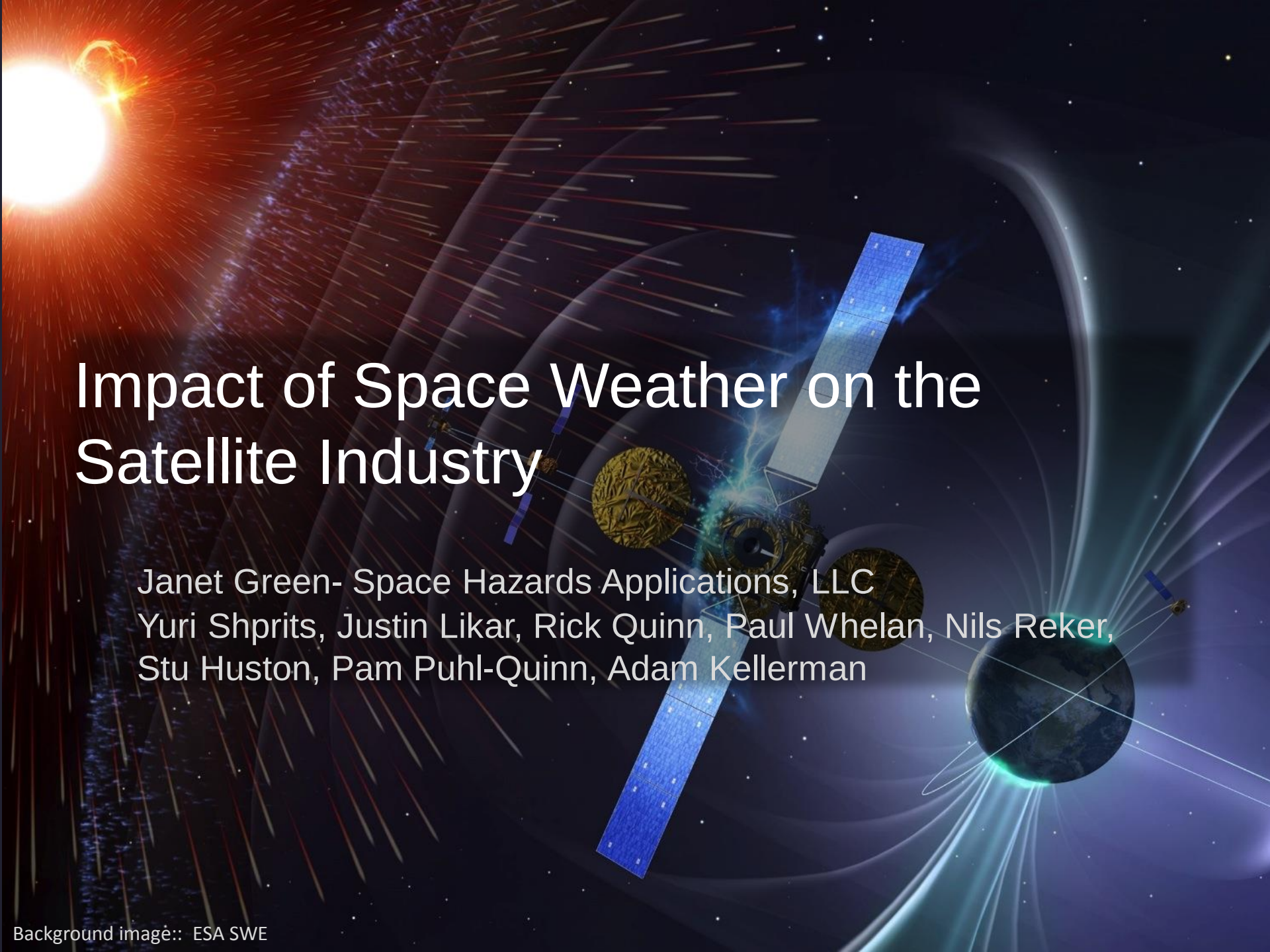
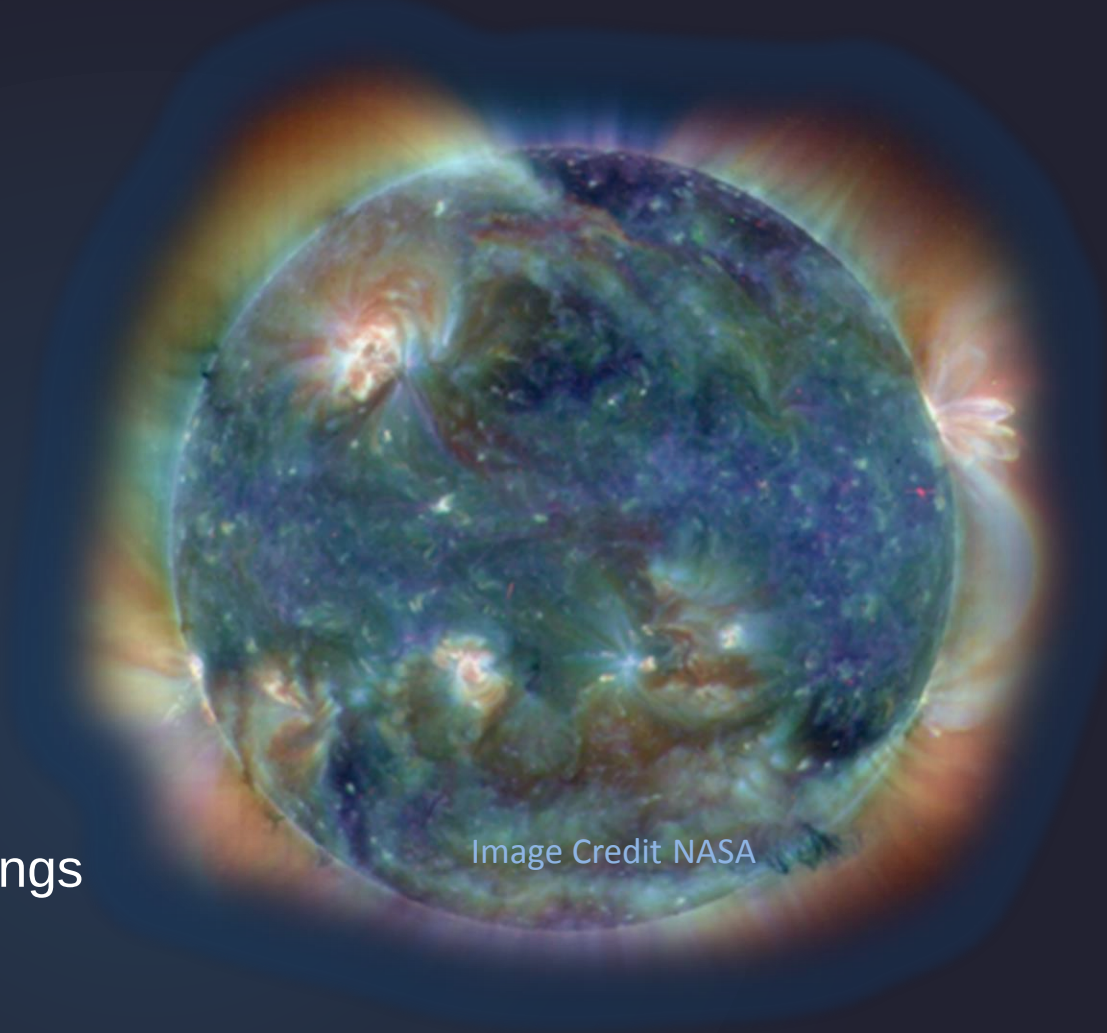


Impact of Space Weather on the Satellite Industry

Janet Green- Space Hazards Applications, LLC
Yuri Shprits, Justin Likar, Rick Quinn, Paul Whelan, Nils Reker, Stu Huston, Pam Puhl-Quinn, Adam Kellerman

Background image:: ESA SWE

Outline



Background
- The Issue
- The Concern
- The Challenge

Projects

SatCAT
- Satellite Industry Meetings
- Forensic tool

SANDI
- Automatic Satellite Anomaly Driver Identification

Anomaly Database

Summary

The Issue

Space weather causes satellite anomalies and disrupts operations

Surface Charging:

Charged particles collect on satellite surfaces producing high voltages, damaging arcs (electrostatic discharges), and electromagnetic interference.

Internal Charging:

Energetic electrons accumulate in interior dielectrics (circuit boards or cable insulators) and on ungrounded metal (spot shields or connector contacts) leading to electrical breakdown in the vicinity of sensitive electronics.

Single Event Upsets:

Energetic ion passage through microelectronic device node causes instantaneous catastrophic device failure, latent damage, or uncommanded mode / state changes requiring ground intervention.

Total Ionizing Dose:

Energy loss (deposited dose) from proton or electron passage through microelectronic device active region accumulates over mission (or step-wise during high dose rate events) causing device degradation and reduced performance at circuit or system level.

Image Credit NASA/SDO

The Concern

Growing Industry and Increasing Reliance

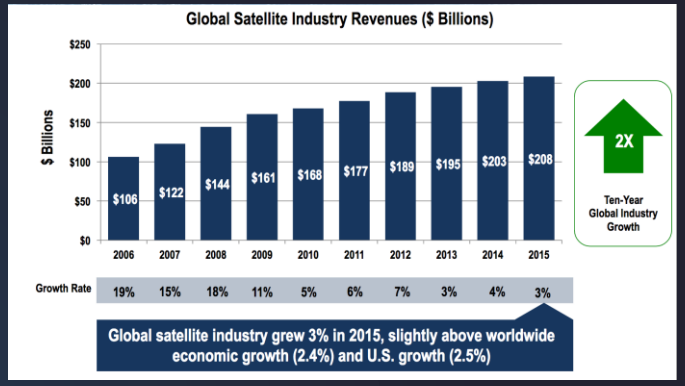
3% growth & 208 B revenue (SIA 2016)

New services with large constellations

- Satellite internet
  - O3B/SES- 12 sats 8000 km (20 planned)
  - Oneweb- planned 720 1200 km (2017 launch)
  - SpaceX- proposed 4000 satellite constellation
- Satellite Imaging
  - Earth observation services revenues grew 10%
  - Digital Globe, Terra Bella, Planet Labs
  - Uses: port traffic, mining development, agriculture, forestry

New Technology

- Electric orbit raising




Credit: Airbus Defense and Space

The Challenge

Effects are caused by distinct particle populations that intensify under varying conditions and in different regions

Surface Charging:

Low to medium energy particles associated with substorms during moderate Kp activity in the dusk magnetospheric regions.

Internal Charging:

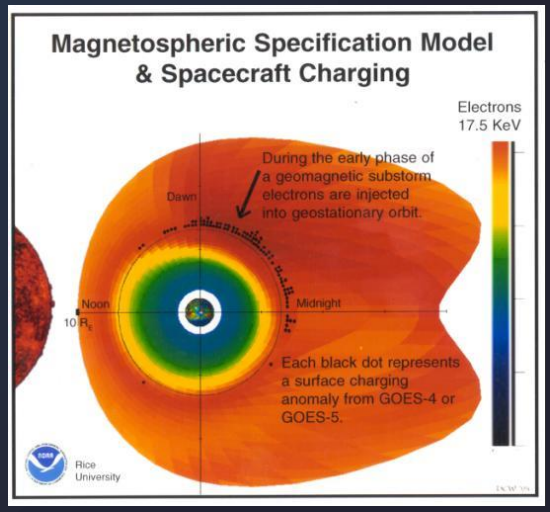
Higher energy electrons associated with some storms that peaks around L=4

Single Event Upsets:

Solar Proton Events associated with solar flares and coronal mass ejections, GCRs, and trapped protons

Total Ionizing Dose:

Trapped protons and electrons and solar proton events



SatCAT Project

The Satellite Charging Assessment Tool

SatCAT project- funded through NOAA Small Business Innovative Research Program.

SBIR- a way to provide innovative solutions to problems not easily addressed within the government framework.

Phase I: (Completed 11/2016)

- Deliver a report on satellite industry needs related to space weather

  Green, J. C., J. Likar, and Y. Shprits (2017), Impact of space weather on the satellite industry, Space Weather, 15, 804–818, doi:10.1002/2017SW001646.
- Build a prototype satellite charging assessment tool

Phase II: (Funded 05/2017-05/2019)

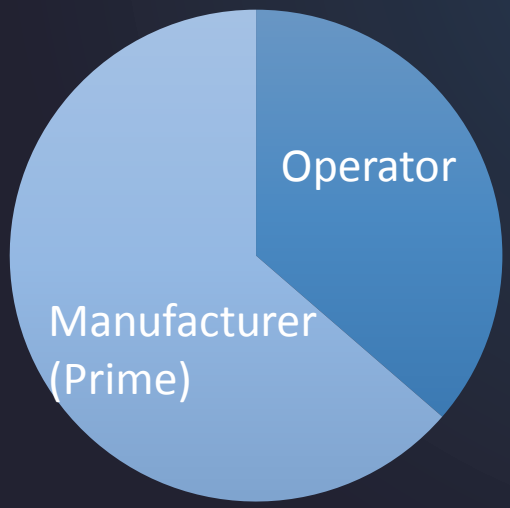
- Continue satellite charging assessment tool development

Industry Meetings

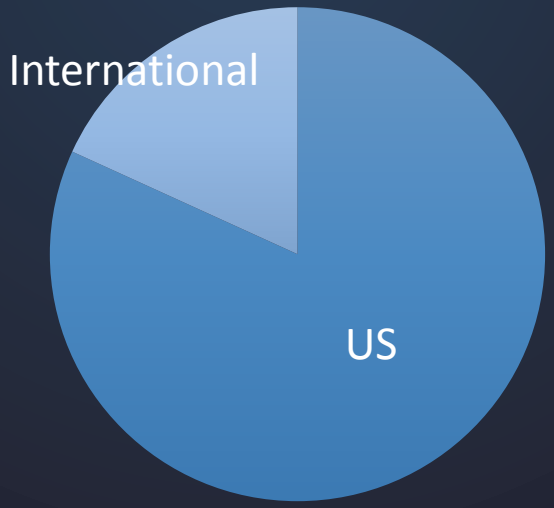
Candid and "as specific as possible" inputs drive end-product utility & effectiveness

- Focused conversations to avoid conference / workshop style setting
- 10 such meetings ensure effective range of inputs, experiences, & needs
- Included survivability engineers, customer/on-orbit response teams
- Greater interest from manufacturers

Mix of Stakeholders



Global reach



Cover LEO to GEO

Findings

Some Findings

- Space Weather Impacts and Severity
- Managing Space Weather Issues

Details and suggested solutions in

Green, J. C., J. Likar, and Y. Shprits (2017), Impact of space weather on the satellite industry, Space Weather, 15, 804–818, doi:10.1002/2017SW001646.

Findings

Space Weather Impacts and Severity

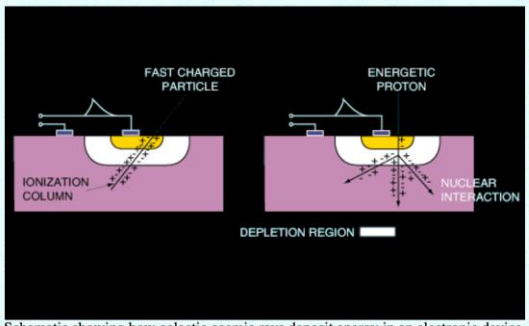
Satellite fleet is robust to space weather impacts but not entirely impervious

- Most impacts are not considered severe or mission limiting and require simple power cycle to correct
- Some are more problematic (not yet in the public domain)

Concern that recent mild conditions promote a false sense of security

SEE were greatest concern/issue

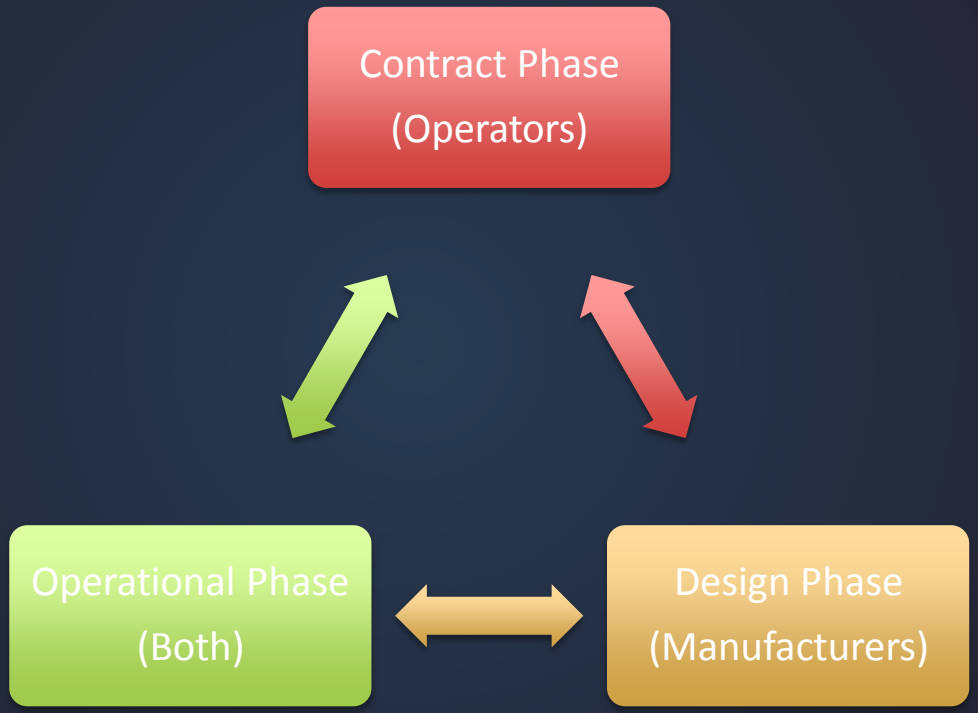
- SEE's are sometimes a catch-all for infrequent unexplained events



Schematic showing how galactic cosmic rays deposit energy in an electronic device.
(Source *Spacecraft Anomalies due to Radiation Environment in Space* by Lauriente and Vampola [19])

Findings

Management of space weather issues is a shared responsibility between manufacturers and operators



The extent and detail of space weather management and response varies greatly depending on the role, the impact, in house expertise, and budget.

Findings

Management of space weather issues is a shared responsibility between manufacturers and operators

Both Operational Phase

Operators

- Monitor telemetry and look for issues
- Confer with manufacturers when anomalies occur
- Investigate response but not cause

Manufacturers

- Customer response team guides actions
- May do simple investigations but cost is not covered in contract
- Larger investigation (ARB) only if impact affects future satellites

Some anomalies go undiagnosed due to

- Lack of specific quick attribution tools and training
- Lack of information sharing between ops and manufacturers
- Lack of anomaly sharing within the industry

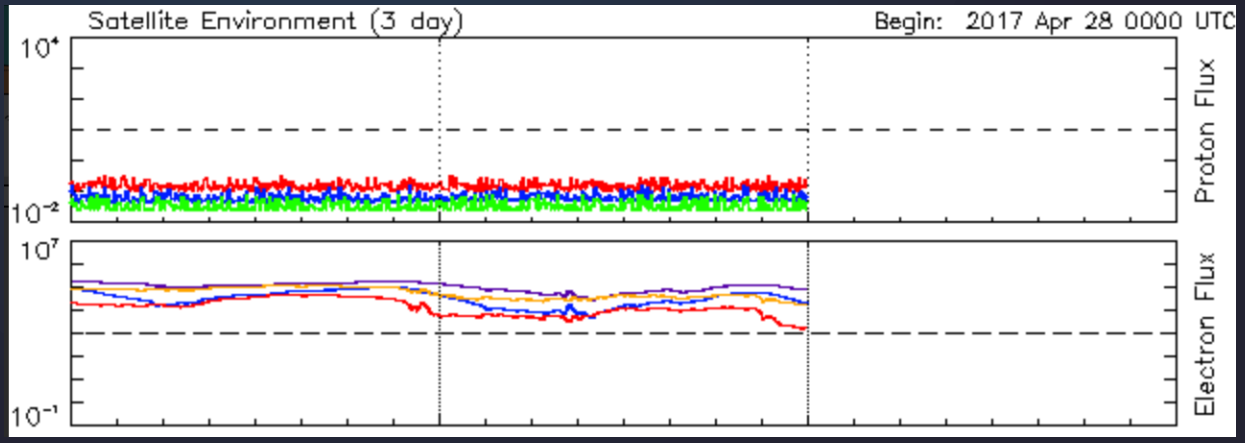
Attribution Challenge

Anomaly Investigation/Monitoring

Current Method:

Most referred to NOAA GOES particle environment plots

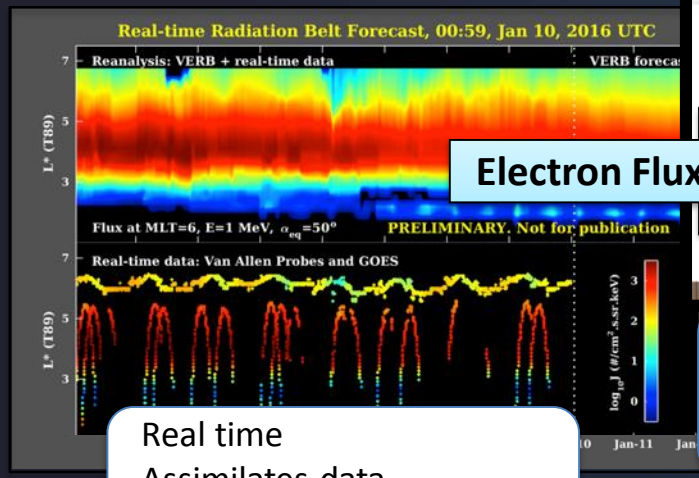
- Difficult to compare to full mission
- Fluxes still need to be translated into one of the four specific hazards
- Fluxes at GEO do not describe full magnetosphere



About SatCAT

Allows you to respond quickly and confidently with the right action

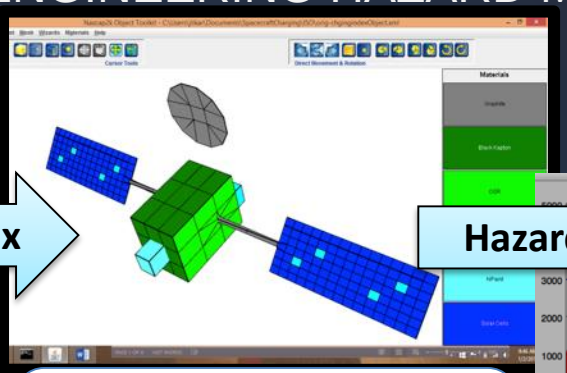
RADIATION DATA/MODEL



Real time
Assimilates data
All orbits nowcast/forecast

Electron Flux

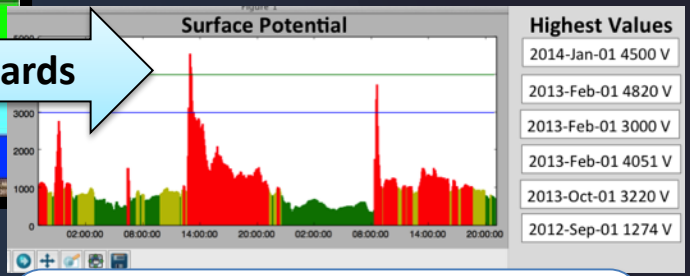
ENGINEERING HAZARD MODULES



Satellite specific
Real charging hazards
Voltage, Accumulated charge

Hazards

DISPLAYS OUTPUTS



Multi-day history
Dates of past highest levels
Comparisons to specs/other events

Combination physics & engineering based approach

End product developed with focus on the customer

How it works

Environment -< Engineering Hazard-< Displays

The Environment

At your satellite along your orbit

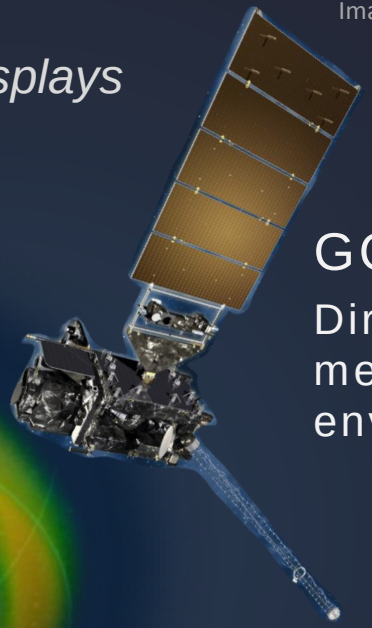


Image Credit NOAA/NASA

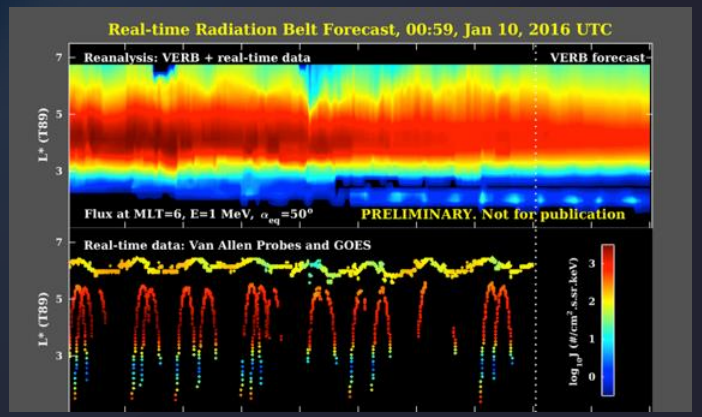
GOES

Direct particle flux measurements specify the environment locally at GEO

Image Credit NASA

VERB

Data assimilative physics based model specifies the environment globally

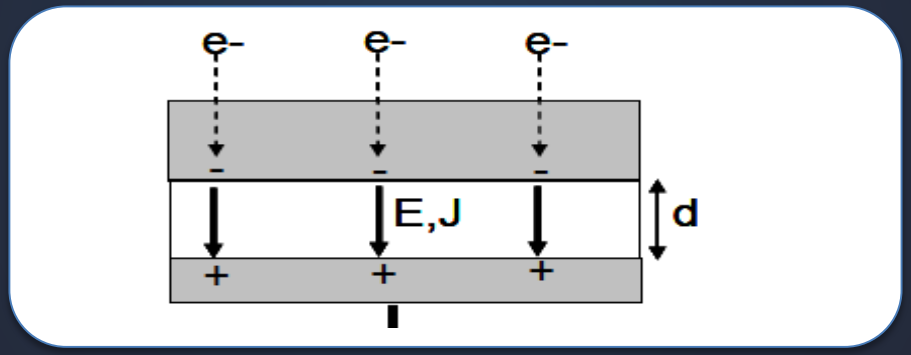


How it works

Environment -< Engineering Hazard-< Displays

The Hazard

At your satellite along your orbit
for your architecture

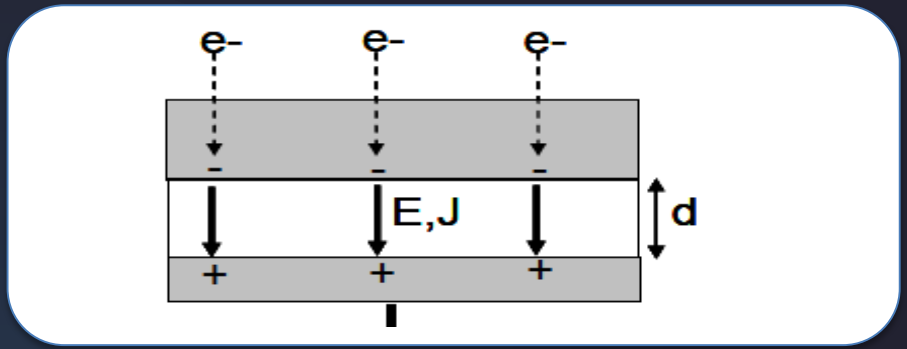


Internal Charging

Total charge accumulation calculated for user chosen layers of shielding and dielectric materials

How it works

Internal Charging



Transfer function

- Defines total flux through shielding for different energies

Bodeau [2010] method

- Charge accumulation treated as an IRC circuit
- Total charge or E field at any time is

$$E(t) = E0*\exp(-t/\tau) + J\rho(1-\exp(t/\tau))$$

τ is dependent on material properties $\varepsilon\rho$

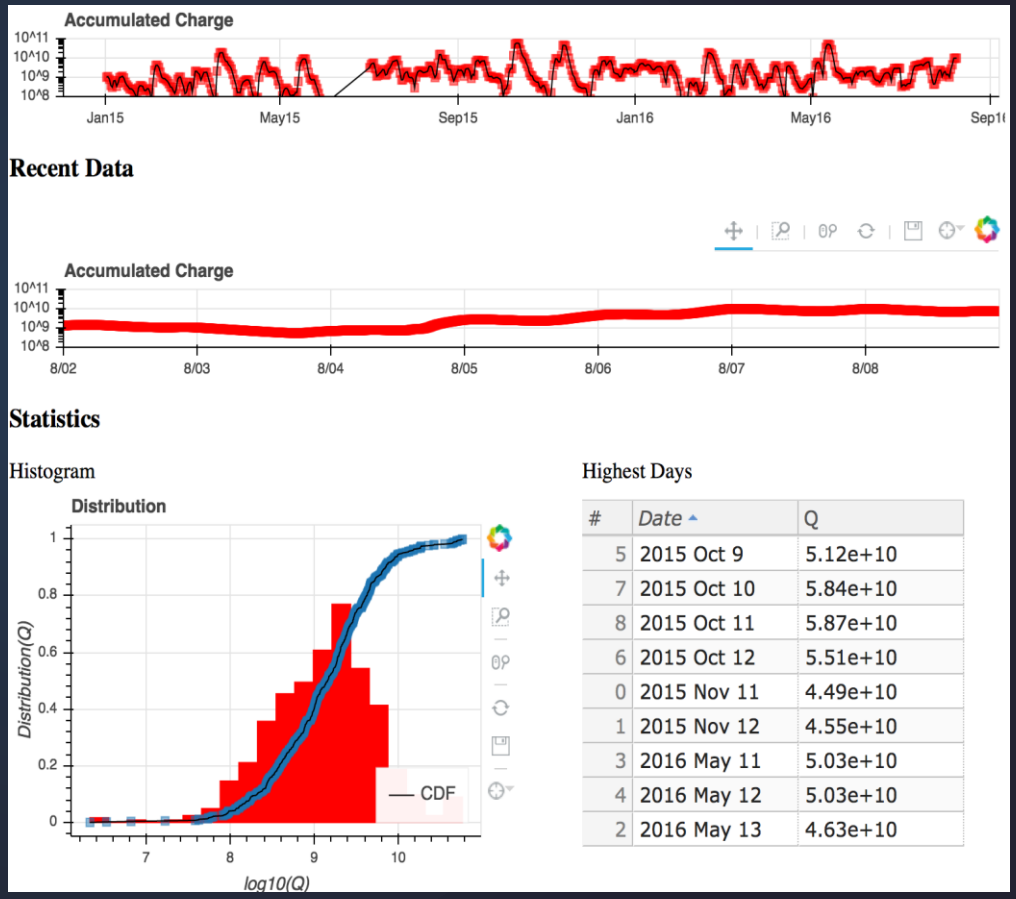
- ESD risk elevated when charge or E reaches critical value

How it works

Environment -< Engineering Hazard-< Displays

Displays

The hazard at the satellite
along its orbit
for its architecture,
thresholds
and events

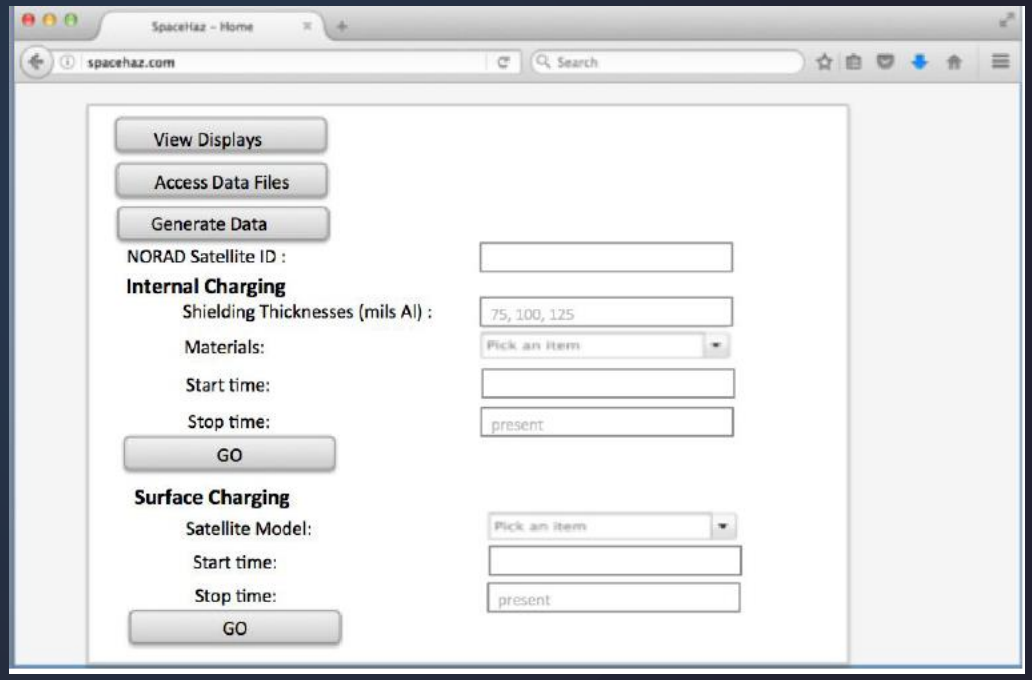


New Development

Making the tool robust, user oriented, and validated

Phase II

- Secure user login
- Generate new data for specified orbits, shielding and materials
- View displays
- Access data
- Add anomaly lists
- User test case and comparison with SCATHA



SANDI Project

Automatic Satellite Anomaly Driver Identification:

GOAL:

To provide government and commercial satellite operators and manufacturers with an automatic optimized tailored forensic tool for determining whether anomalous behavior of specific satellites or satellite fleets is caused by the space particle radiation environment.

AFRL SBIR Phase 1: Sep 2017-May 2018

SANDI Approach

Automatic Satellite Anomaly Driver Identification:

Use statistical relationships between measured drivers/fluxes and anomalies to generate specific satellite/fleet hazard indicators.

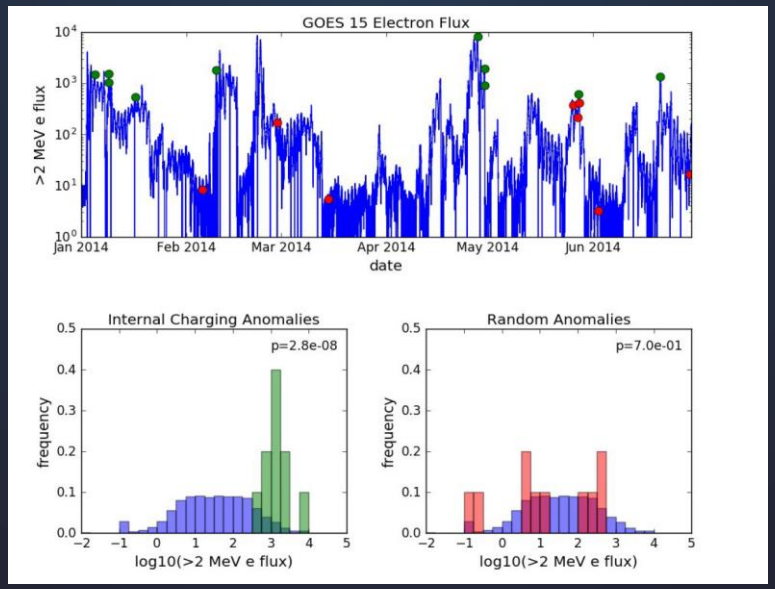
Automated tool will take as input modeled or measured particle fluxes and an anomaly list and output the likely driver and hazard quotient [Obrien, 2009].

SANDI Approach

Automatic Satellite Anomaly Driver Identification:

Three steps:

1) Transform data into possible drivers (Phase 1)
2) Identify likely anomaly drivers (Phase 1)
3) Define the hazard onset (Phase 2)



Anomaly Database

Community Coordinated

What is it?

A community coordinated satellite anomaly database is a repository or collection with the time history of issues that have occurred with satellites on orbit related to the environment.

What is the purpose?

To help identify the cause of satellite anomalies.

What is the benefit?

Satellite anomalies are sometimes infrequent making it challenging to identify the root cause. Grouping issues can reveal environmental correlations that indicate the cause and guide response and mitigation.

Background

Previous/Ongoing Efforts

Collecting anomaly info is not a new idea. Some examples are below.

- NOAA NCEI (formerly NGDC) maintained a collection through 1993 https://www.ngdc.noaa.gov/stp/satellite/anomaly/satelliteanomaly.html
- Space News Digest http://www.sat-nd.com/
- Private Insurance Collections (ASIC)

Other resources

- RAND Report: Satellite Anomalies Benefits of a Centralized Anomaly Database and Methods for Securely Sharing Information Among Satellite Operators http://www.rand.org/content/dam/rand/pubs/research_reports/RR500/RR560/RAND_RR560.pdf

What is new now?

Proposed large satellite constellations (100+) carry potentially greater risk and also offer better statistics for inferring environmental correlations.

Tools/techniques exist that can use the anomaly information.

Some momentum and interest

- CGMS- has requested that members report satellite anomalies
- UNCOPUOS- has recommended that member states support and promote satellite anomaly and space weather effects reporting
- US SWAP- DOC /DOD will create and support a satellite anomaly database to enable secure collection and analysis of satellite anomaly data related to space weather
- Acknowledged interest by some commercial companies

Other successful examples of community coordinated resources

- Satellite Data Association has created the Satellite Data Center that provides members with conjunction assessment, RF interference and geo-location support, and authoritative contact information for a given space object based on user contributions

Community Discussion(s)

What is the purpose?

To collect input and ideas for how to create a community coordinated anomaly database.

What is the expected outcome?

A blueprint for what such a resource should look like and a path forward to implementing it.

Who should give input?

All those interested in the benefit of a database.

https://goo.gl/forms/4DUQVqodHqw1cdMv2

When/where will discussion(s) take place?

European Space Weather Week (11/2017)

Other community meetings as needed

- NOAA Space Weather Week?
- Online Discussions?

Summary

Changes in satellite industry increase space weather concerns

Forensic Tools Being Developed:

For operators/designers who need to maintain mission operations and resolve unavoidable satellite anomalies, SatCAT and SANDI are tools that summarizes space weather impacts to specific asset to quickly make confident decisions.

SatCAT

- Describes internal charging hazard for specific satellite properties
- Available May 2019

SANDI

- Automatically identifies drivers and hazards from statistical correlations between measured/modeled data and anomaly lists

Satellite Anomaly Database

- Please provide input by filling out a paper from or online survey https://goo.gl/forms/4DUQVqodHqw1cdMv2