Long term and short term forecasts of the radiation and plasma environment near Earth: Identifying needs and delivering value

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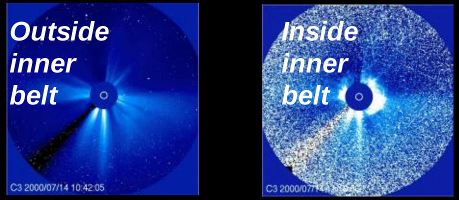
Outline

- Introduction to Hazards
- Long Term Forecasts (Climatology)
- Short Term Forecasts (Weather)
- Launch Considerations
- Recommendations

Space Environment Hazards

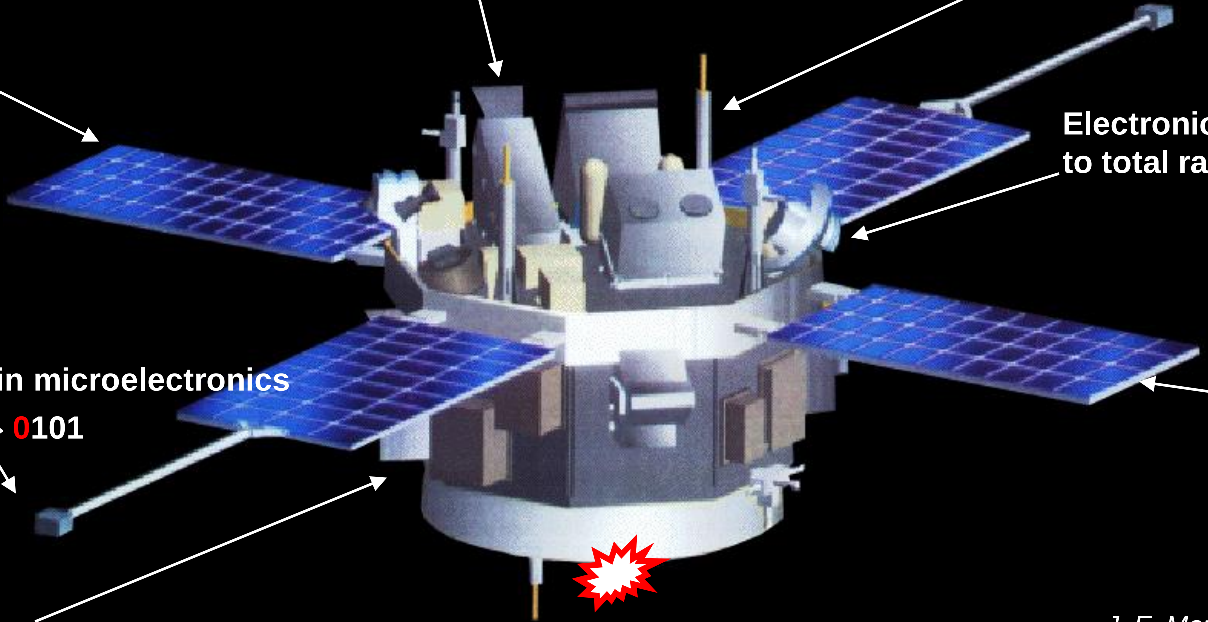
False stars in star tracker CCDs



before *after*

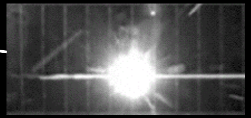
Surface degradation from radiation

Solar array power decrease due to radiation damage



Electronics degrade due to total radiation dose

Solar array arc discharge



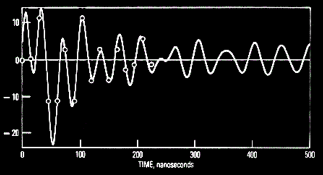
Single event effects in microelectronics

1101 ⇒ 0101

Spacecraft components become radioactive

Electromagnetic pulse from vehicle discharge

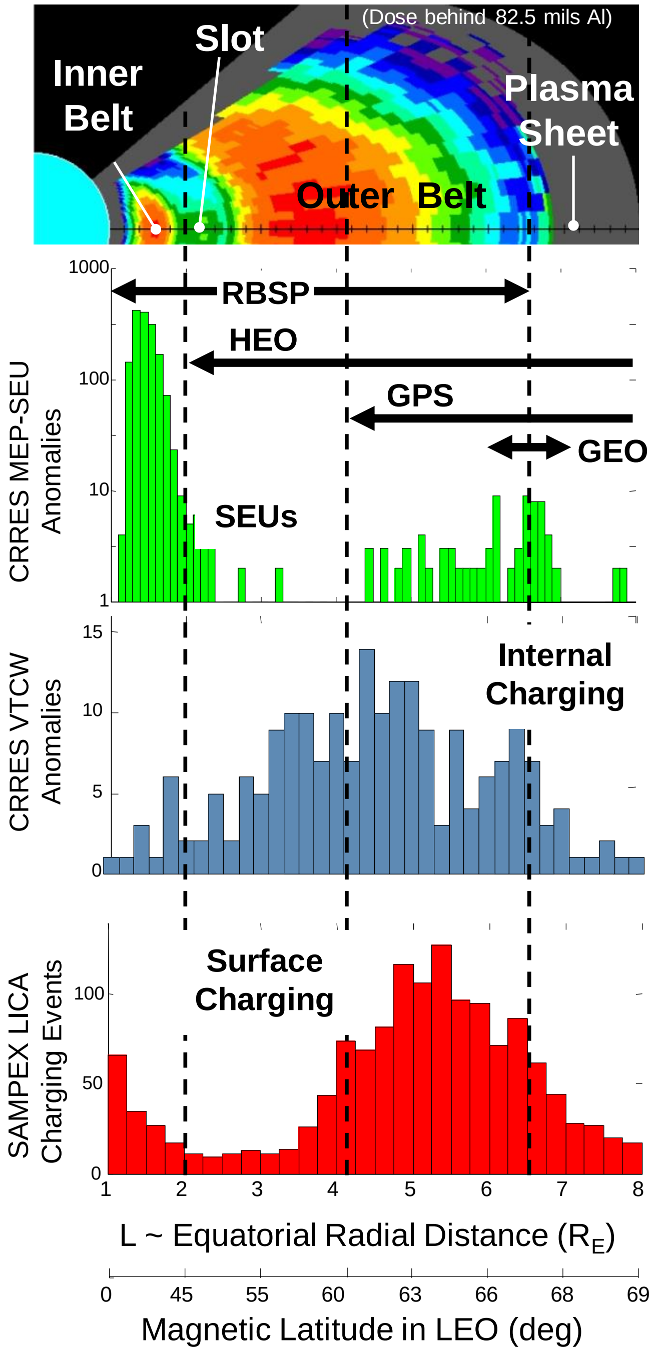
Induced Voltage



Time

J. E. Mazur, J. F. Fennell, & P. O'Brien, Proc. 31st Annual AAS Rocky Mountain Guidance and Control Conference, vol. 131, M. E. Drews & R. D. Culp Eds., 2008

Hazard Climatology by Location

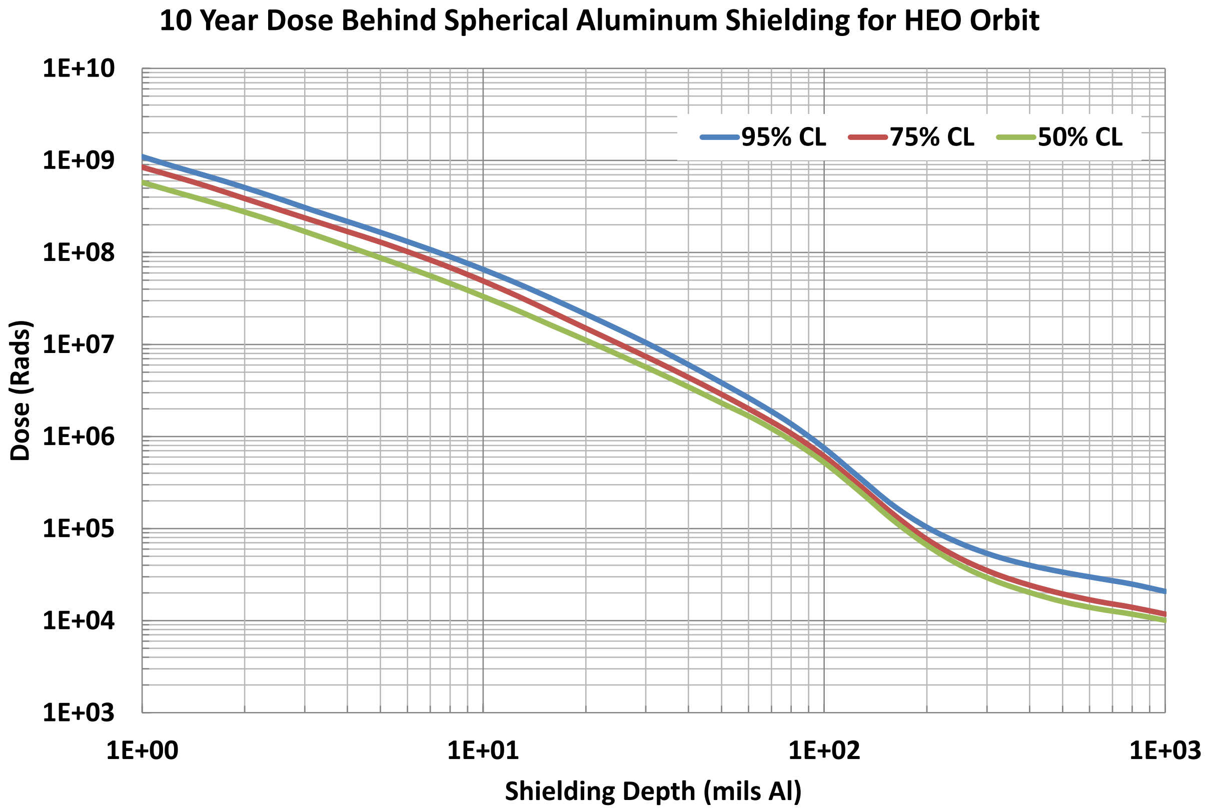


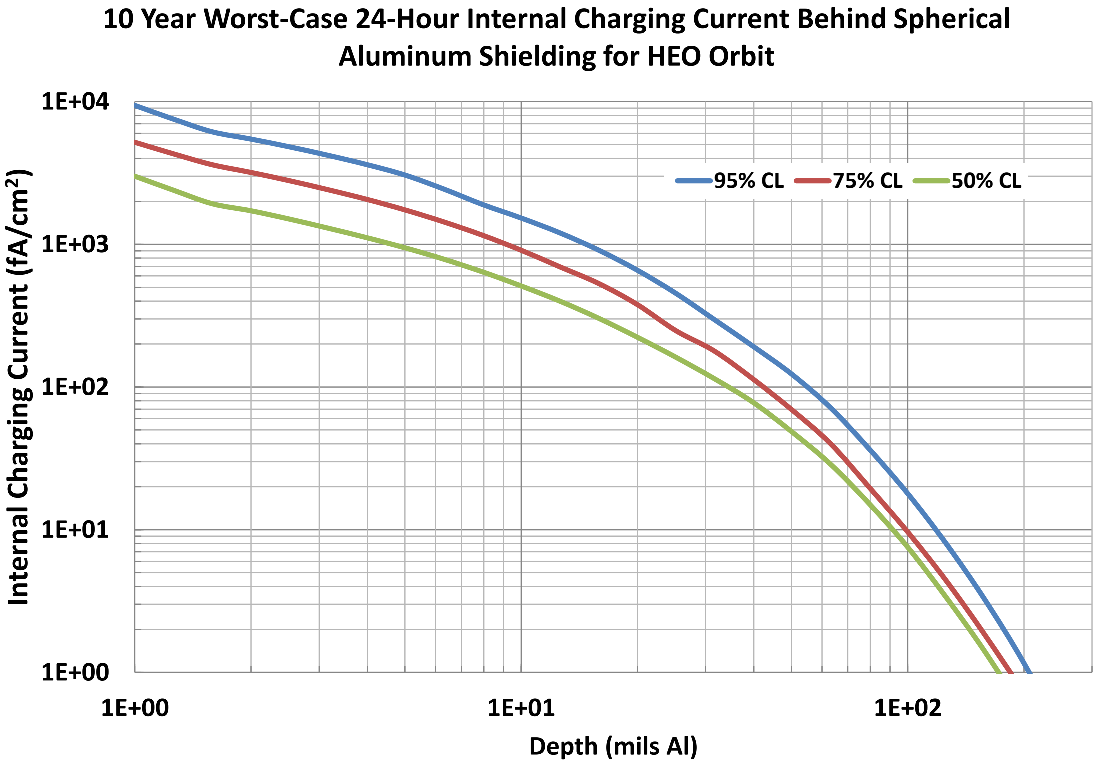
- Event Total Dose
  - *Caused by ~MeV electrons and multi-MeV protons*
  - *Driven by flux intensity*
  - *Requires hours to days of accumulation*
- Single Event Effects
  - *Caused by multi-MeV protons and heavy ions*
  - *Driven by flux intensity*
  - *Instantaneous*
- Internal Charging
  - *Caused by >0.1 MeV electrons*
  - *Driven mainly by flux, affected by spectrum and materials*
  - *Typically requires hours of accumulation, but large variation*
- Surface Charging
  - *Caused by keV electrons*
  - *Usually diagnosed with L, MLT or local temperature/spectrum*
  - *Heavily influenced by material properties, which change on orbit!*
  - *Shadow, timing and location are hugely critical*

Long Term Forecasts: Climatology

Nature of Forecast	Statistics: mean, worst case	Years to Decades
Use	Satellite designers	Assess and Mitigate Risk
Approach	Empirical	Sometimes captured in standards: military, NASA, ESA, ISO
Quantities Forecast	• Total mission fluence of electrons, protons, heavy ions, at desired confidence level • Worst minute proton and heavy ion flux, at desired confidence level • Worst day electron flux, at desired confidence level • Worst minute plasma conditions (reference worst case)	Derived quantities: • dose, • displacement damage, • single event effects rate/probability, • internal charging current or potential, • surface charging potential
Funding	Split between civilian and national security	• National security funds AE9/AP9-IRENE (trapped radiation and plasma) • NASA funds ESP-PSYCHIC (solar particles) and Badhwar-O'Neill (GCR)

Long Term Forecasts –HEO/Molniya Examples





- Total radiation dose is a primary consideration for most satellite designs
- It is derived mainly from the mean environment
- It affects shielding and part choice
- Provided here by AE9/AP9 and ESP

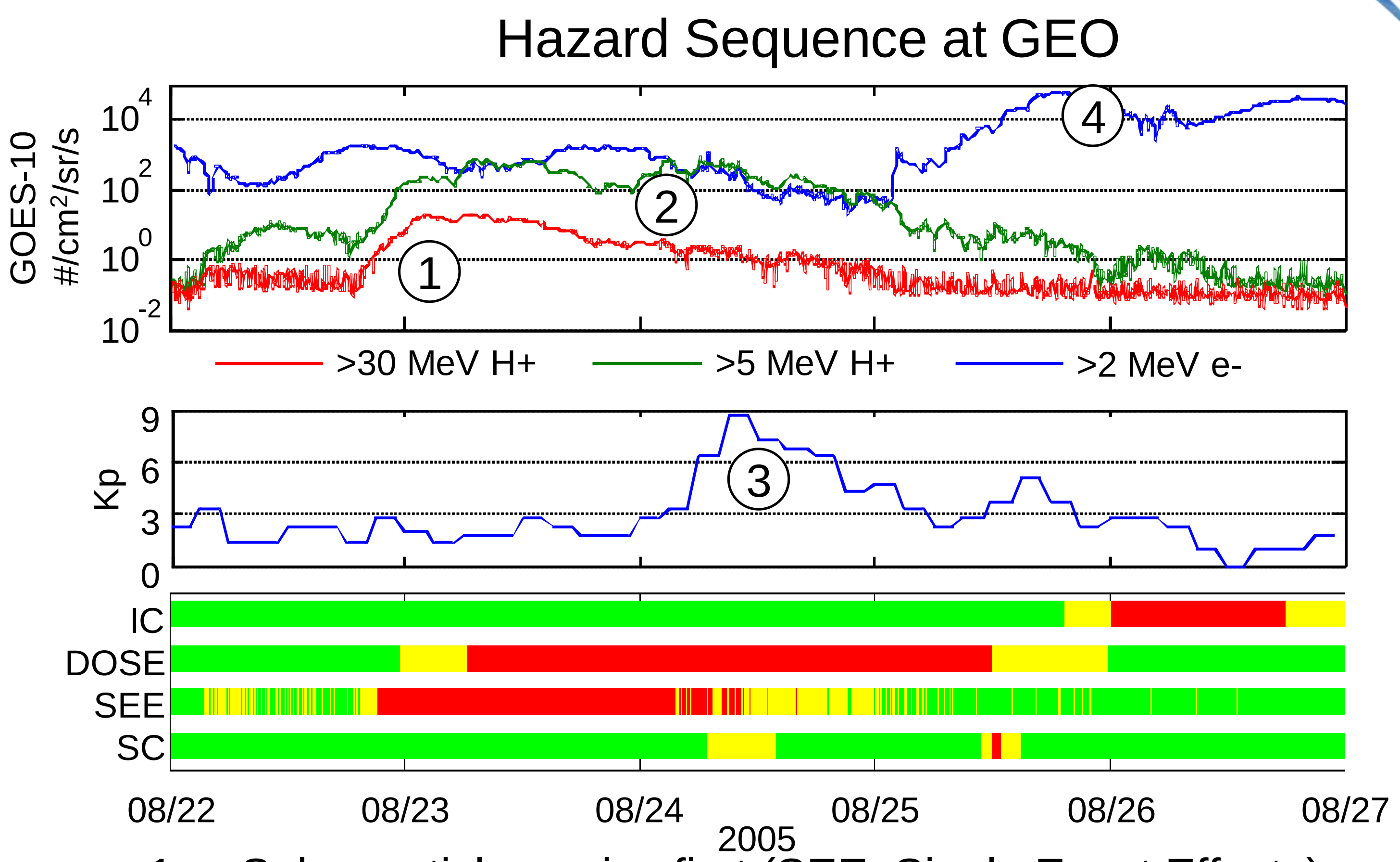
- Internal charging current is derived from the transient environment (e.g., worst day)
- It affects shielding and material choice, and electrical system design
- Provided here by AE9

Short Term Forecasts: Weather

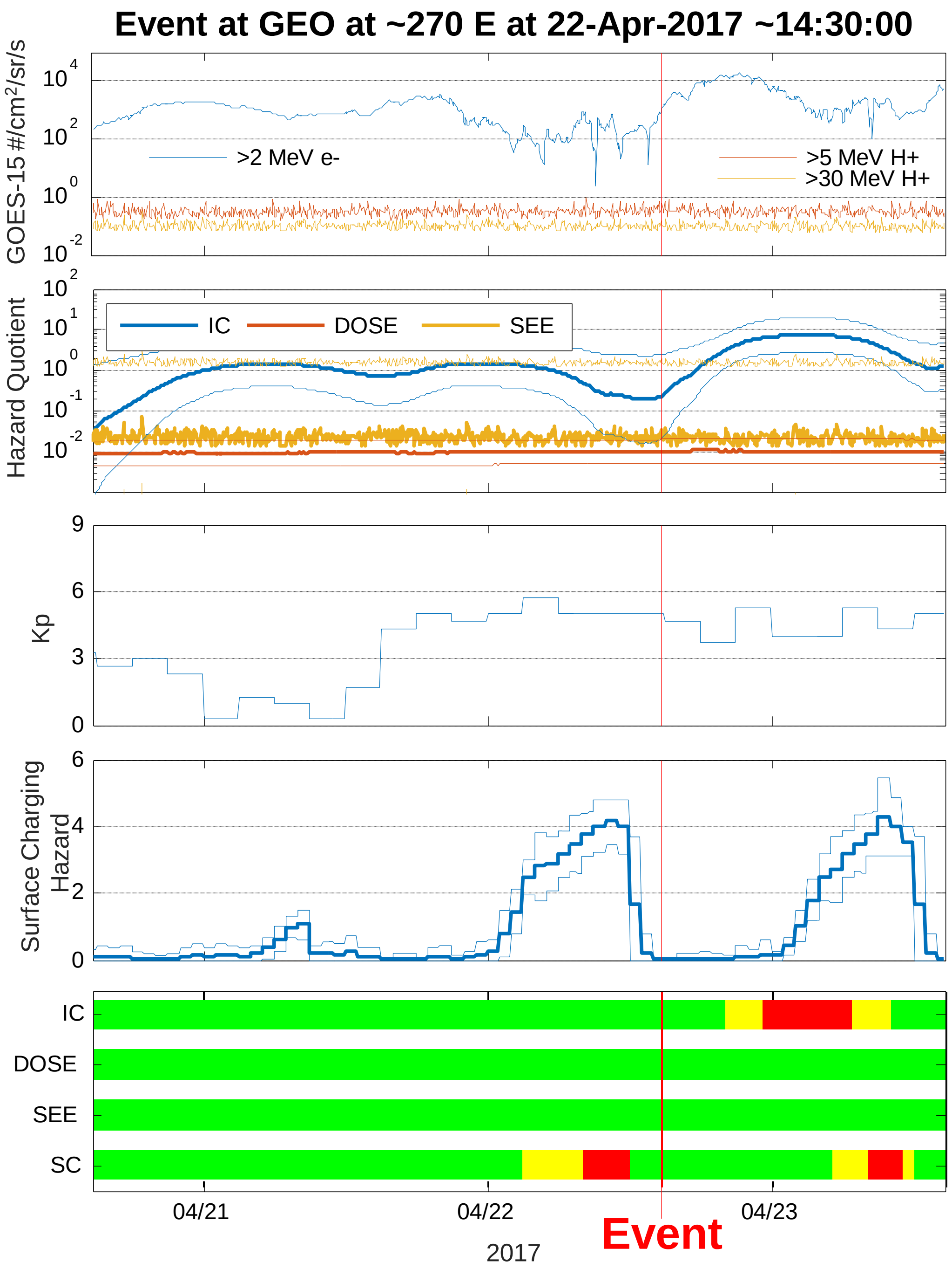
Nature of Forecast	Specific events	Minutes to days
Use	Satellite operators (rarely) Launch (desired)	• Anomalies are rare • Connection to elevated environments is weak • All clear for risky operations is best use case, e.g., launch
Approach	Mix of physics-based and empirical models	• Physics-based are global, but less accurate • Empirical are local, but more accurate • Data assimilation promises to provide best of both worlds
Quantities Forecast	• Event onset • Flux time series through some or all of Geospace	We need a good forensic tool • Scientific focus on forecast has left us with crude tools to reconstruct what just happened during an anomaly • Need a tool that seamlessly represents environment at vehicle from launch until now • This enables development of statistical rules that could be used to exploit forecasts
Funding	A complex mix	• Fundamental research funded mostly by NASA, NSF • Real-time and forecast models developed on NASA, NSF, and agency funding • Situational awareness and forensic tools funded in house at NOAA, NASA, AFRL, Aerospace, etc • (European approach draw from whole community's expertise across all three)

Short Term Forecasts – SEAES Tool

- This is an example of The Aerospace Corporation's Spacecraft Environmental Anomalies Expert System
- It addresses the four major space weather hazards to satellites
- Versions of it run at NOAA/SWPC, NASA/GSFC, and in defense systems
- Its scope is presently limited to specific orbits where near-real-time data are available
- It seamlessly integrates a very rudimentary forecast (persistence-on-orbit) with the vehicle's recent or entire history, depending on the implementation



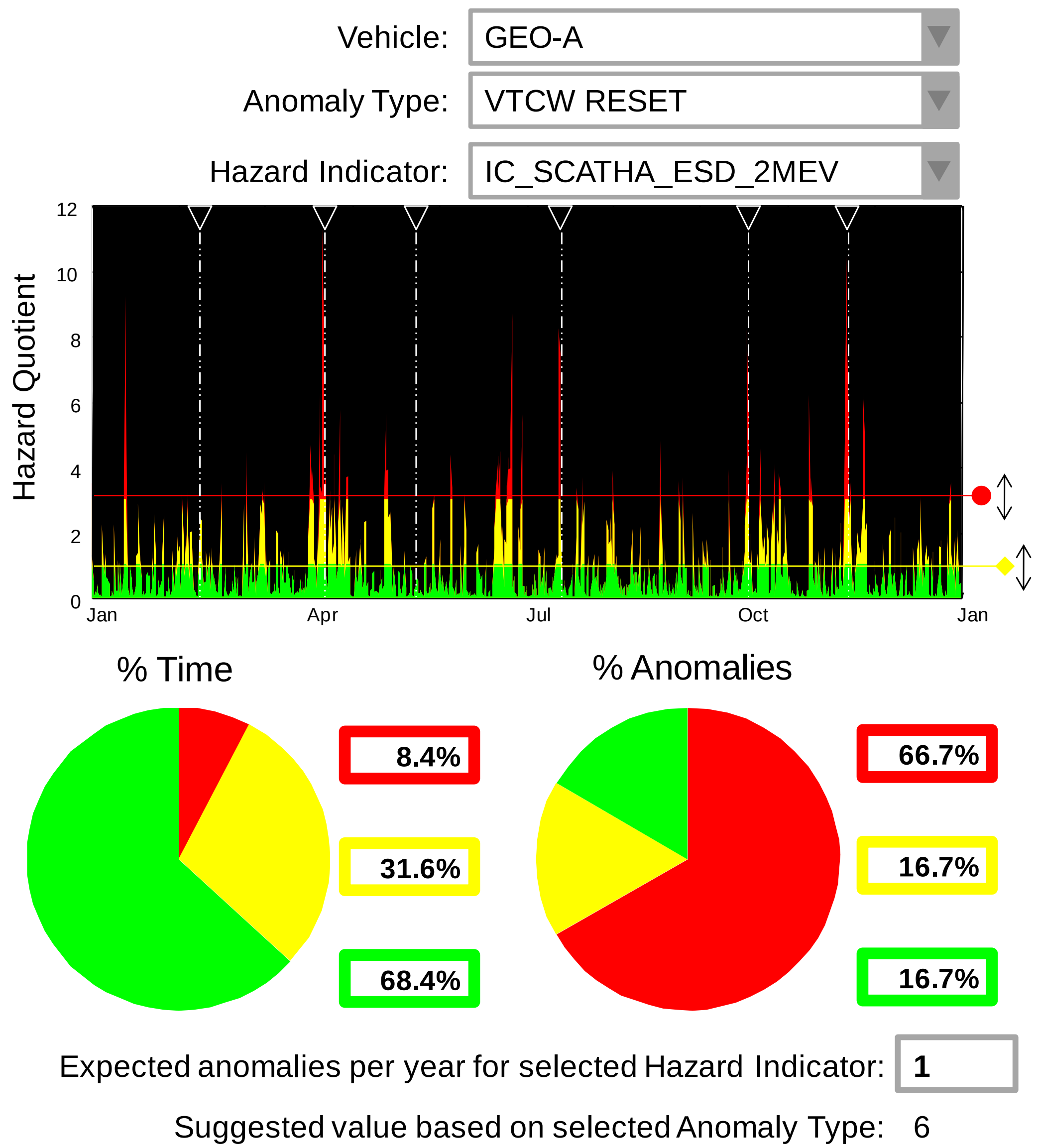
1. Solar particles arrive first (SEE: Single Event Effects)
2. Solar particle dose accumulates (DOSE : Event Total Dose)
3. Geomagnetic storm occurs (SC: Surface Charging)
4. Trapped electrons increase (IC: Internal Charging)



Merging Forecast and Forensics

- In this example, an event at GEO is analyzed using the exact same algorithms and displays as the short term forecast tool
- The anomaly occurred at a time when none of the hazards was expected to be elevated, for a typical vehicle
- The preliminary conclusion is that this event was *not* caused by space weather

Forensics: A Big Missing Piece



- Reconstructing the recent environment, much less the environment since launch, remains largely an ad hoc process, depending on orbit regime
- Such reconstructions are essential for forensics
- The example tool at left allows an analyst to set red/yellow thresholds based on a hazard indicator and a series of suspected environmental anomalies
- Other forensic tools would assist in day-of-anomaly analysis and in constructing hazard indicators and their relationships to anomaly probability
- Without these tools, forecasts are just curiosities

FORENSICS + FORECAST = ACTION

Launch – A Critical Case

- Launch operations care primarily about a high confidence “All Clear”
- Launch Commit Criteria suffer from weak connection between space weather conditions and vehicle vulnerabilities
- It is unknown whether dependence on enterprise assets (ground comm, sat comm, sat nav) exposes the launch campaign to broader risks beyond the launch vehicle and its payload
- There are no tools to aid day-of-launch decisions
  - *Where/when/will the vehicle encounter hazardous conditions?*
  - *Will those conditions exceed vehicle specifications?*

- Ignorance of environment and its effects leads to invalid holds and scrubs

- These expensive mistakes are consequences of inadequate decision support tools and susceptibility analysis

- We are not experiencing the converse mistakes: there are no known launch anomalies caused by space weather

Recommendations

- To achieve societal benefit, engage users and build relationships
  - *Relationships must be deeper than alternating monologues at conferences and workshops*
  - *Have joint workshops, e.g., between IEEE NPSS and AGU SPA*
  - *We are seeing more of this, e.g., CCMC ILWS workshop, ASEC, SEESAW*

- Be mindful of the difference between forecast as a demonstration of scientific prowess versus forecast as a user-support activity
  - *Scientific understanding favors physics-based simulations*
  - *User-support often prefers empirical models (faster, more accurate)*

- Align responsibilities and funding for short term forensics, short term forecast, and launch ops
  - *Too often we rely on “low hanging fruit” and “throwing a model over the fence.” This does not work*
  - *The organizations that rely on short term forecasts are often unable to fund related research and R2O*
  - *No one institution can do it all alone*
  - *Open up funding to external collaboration*