Radiation and Plasma Hazards to Satellites in the Declining Solar Cycle

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Outline

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- High Speed Streams and Magnetospheric Particle Hazards
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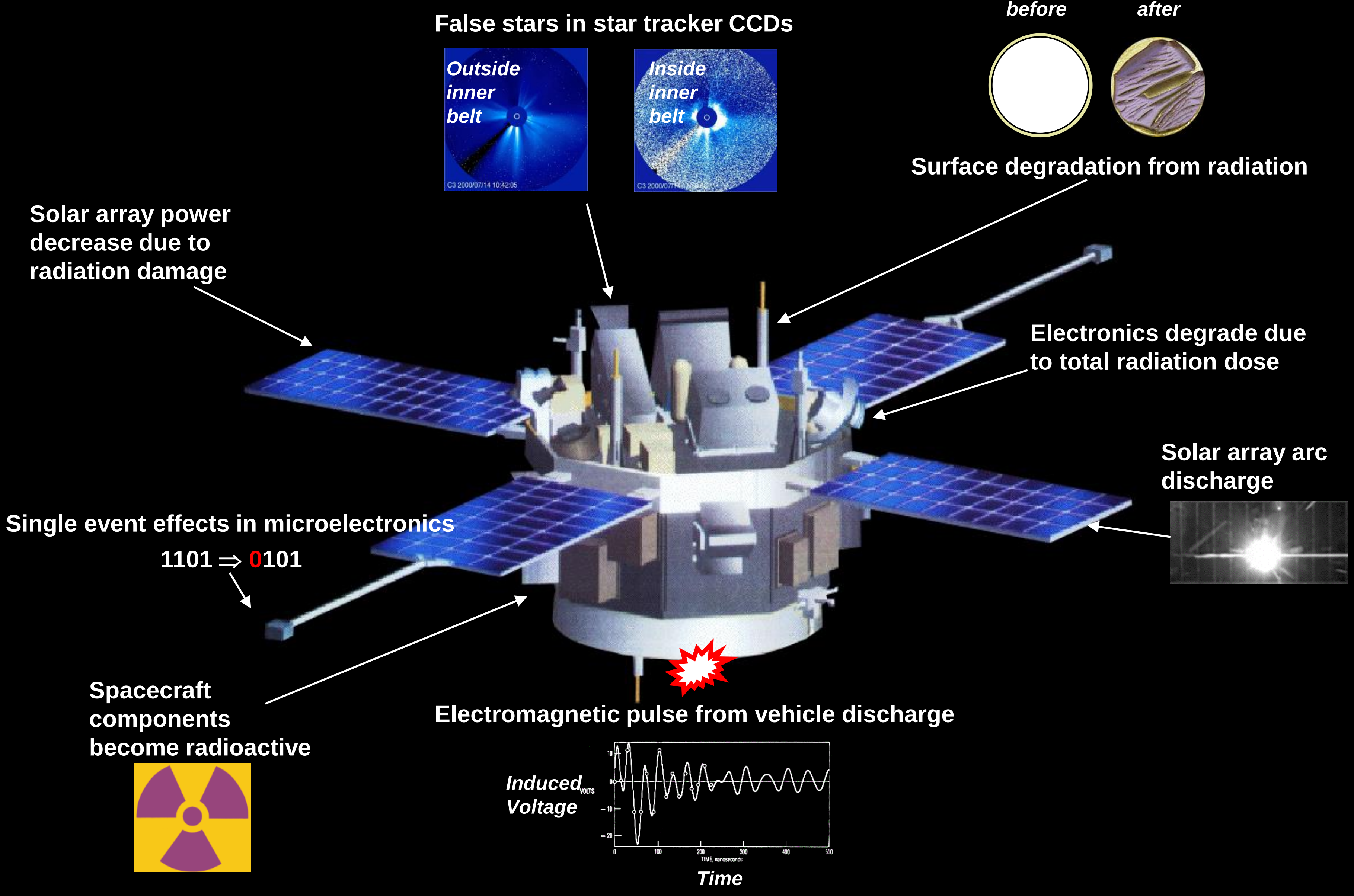
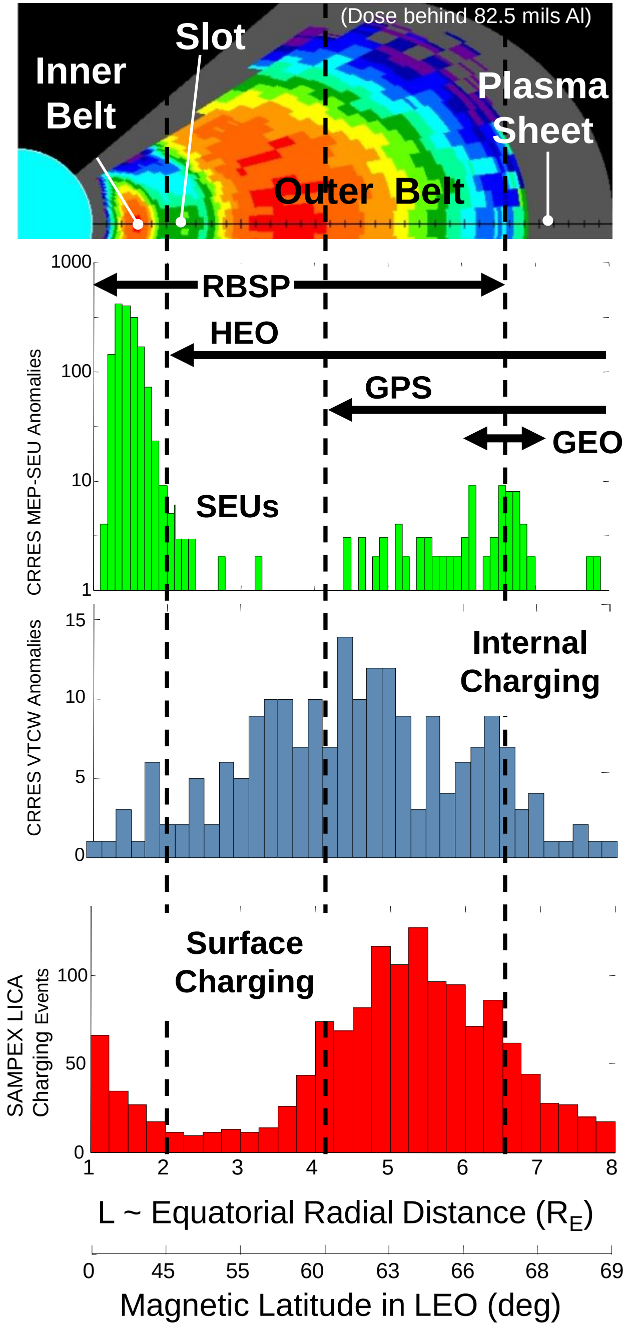
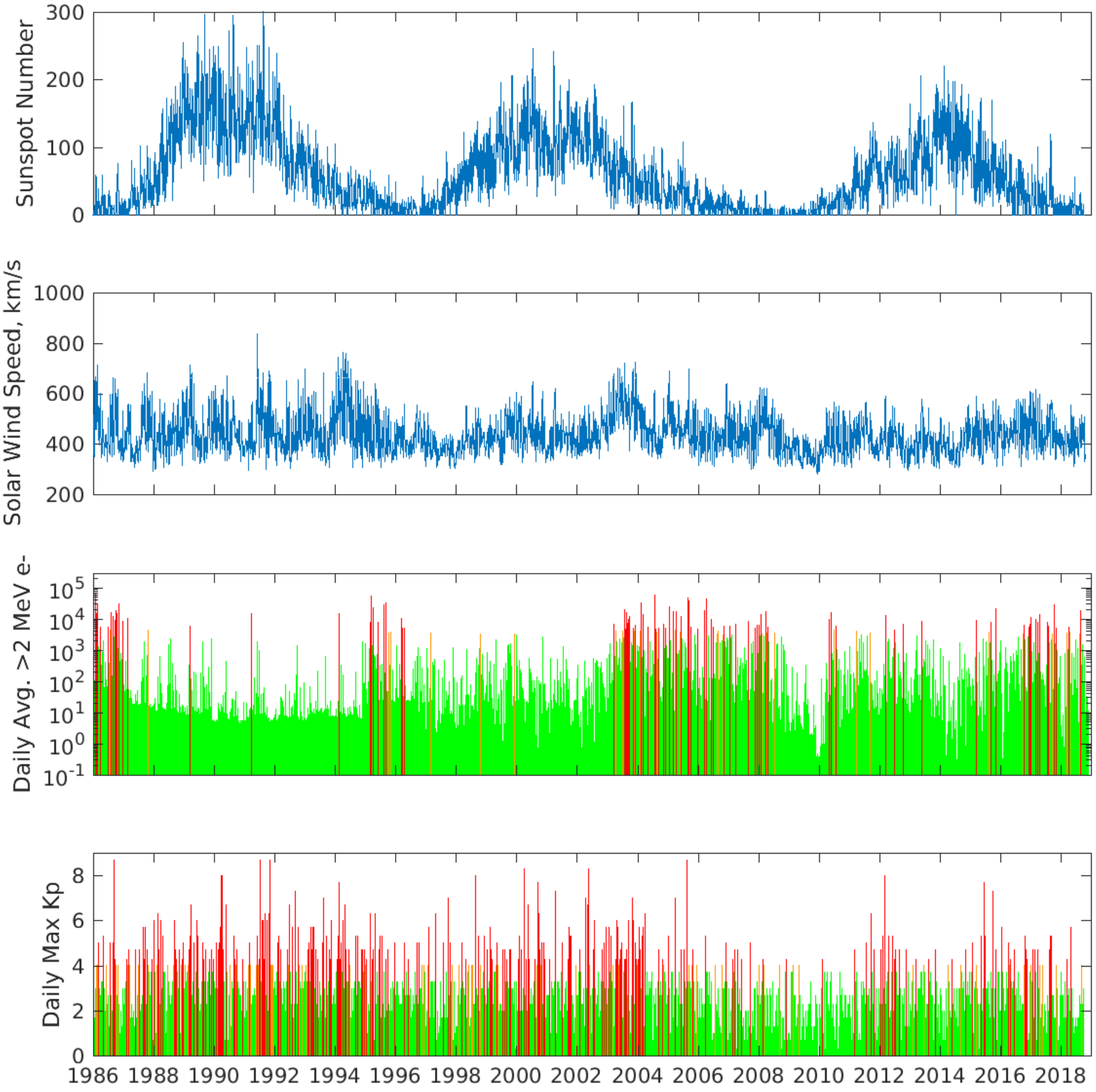
Radiation and Plasma Hazards to Satellites





Magnetospheric Particles and Hazards

- Event Total Dose (DOSE)
  - *Caused by ~MeV electrons and multi-MeV protons*
  - *Driven by flux intensity*
  - *Requires hours to days of accumulation*
  - *Typically need evidence in same region of radiation belts*
- Single Event Effects (SEE)
  - *Caused by multi-MeV protons and heavy ions*
  - *Driven by flux intensity*
  - *Instantaneous*
  - *Typically need evidence in same region of radiation belts*
- Internal Charging (IC)
  - *Caused by >0.1 MeV electrons*
  - *Driven mainly by flux intensity*
  - *Requires hours of accumulation*
  - *Typically need evidence in same region of radiation belts*
- Surface Charging (SC)
  - *Caused by keV electrons*
  - *Can be driven mainly by spectral shape, not flux intensity*
  - *Usually diagnosed with location or local electron spectrum or average energy*
  - *Timing and location are critical*

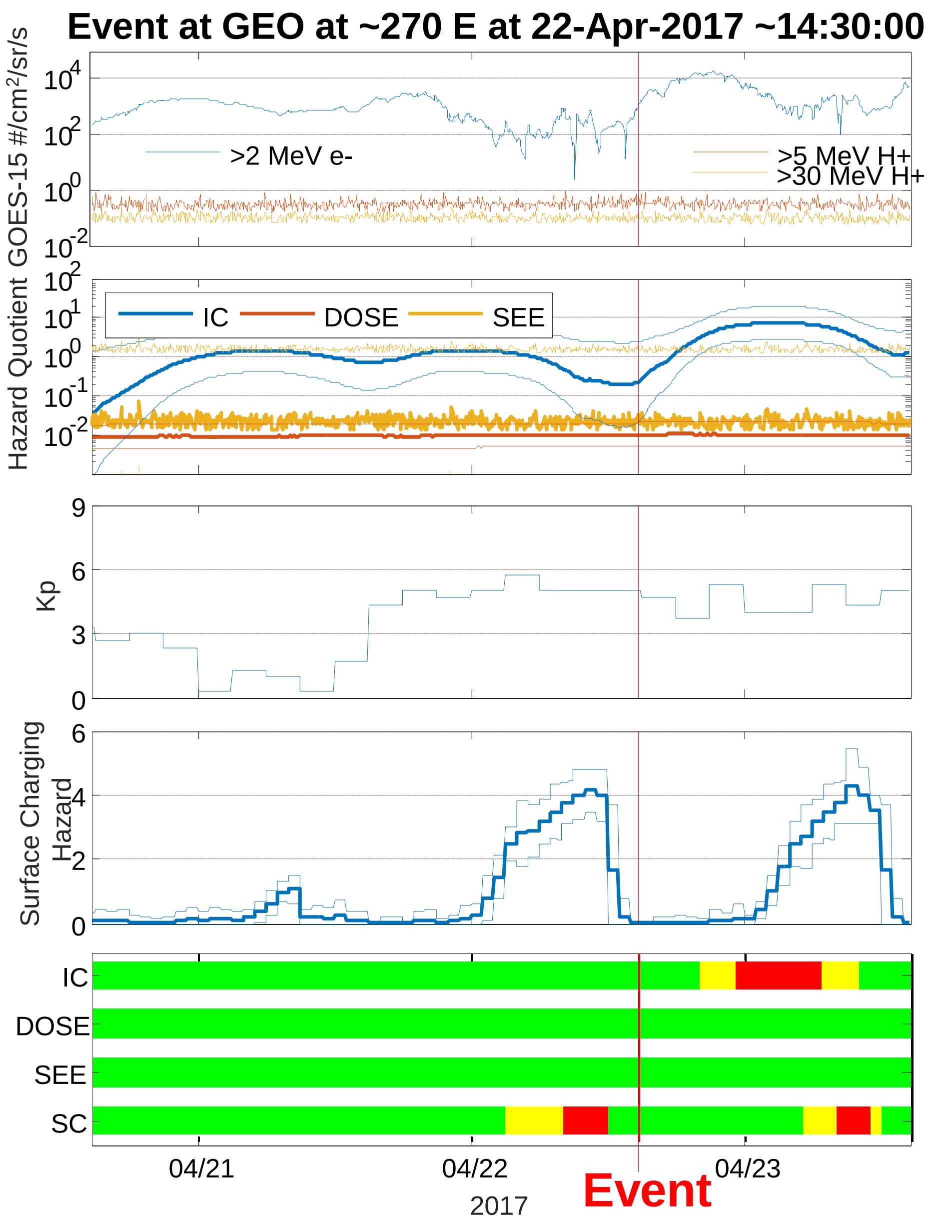


High Speed Streams and Magnetospheric Particle Hazards

- High speed streams are an underappreciated hazard to satellites: much of the focus of Space Weather research is on eruptive events (flares and CMEs)
- High speed streams have long been known to drive intense outer belt electron fluxes, which causes internal charging
- They also drive significant enhancements in plasma convection from the tail to the inner magnetosphere (HILDCAA), leading to surface charging
- These hazardous conditions (PSALMSS) can last much longer during HSS than during typical CMEs

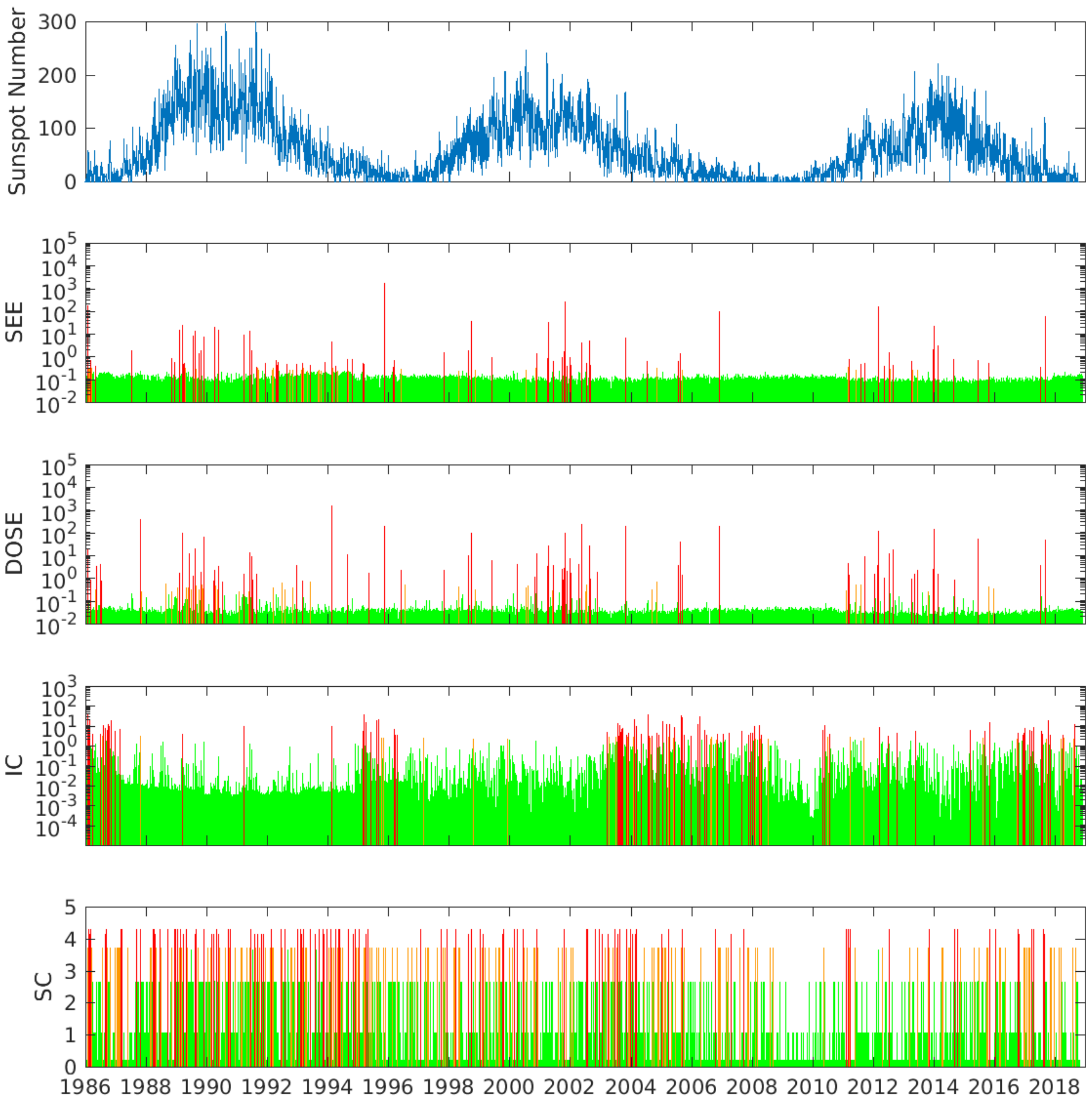
- See Paulikas and Blake, *Geophys. Mongr. Ser.* 1979; Tsurutani and Gonzalez, *Planet. Space Sci.* 1987 (HILDCAA); Meredith et al., *JGR,* 2003 (PSALMSS)

Modeling Anomaly Rates at Geostationary Orbit with SEAES



- The Spacecraft Environmental Anomalies Expert System (SEAES) for Geostationary Orbit uses GOES data and Kp to estimate anomaly hazards
- Each SEAES rule relates environmental parameters to the probability of an anomaly
- Rules are built from statistics of previously observed anomalies or their proxies
- SEE: drive by >30 MeV protons (GOES)
- DOSE: driven by >5 MeV protons (GOES)
- IC: driven by >2 MeV electrons (GOES)
- Kp: driven by Kp and vehicle local time

- See O'Brien, *Space Weather* (2009)



How Anomaly Rates at Geostationary Orbit Vary over the Solar Cycle

- Here we have anomaly rates per year, assuming an average of 1/year in each category
- SEE and DOSE anomalies are clustered near solar max, but with some risk any time (note the log scale)
- IC anomalies are more prevalent in the declining phase and near solar min
- SC anomalies are scattered throughout the solar cycle, with a weak preference for solar max

Summary: How is the declining phase different?

- For satellite anomalies, eruptive events are only half the story, and the other half becomes very important during the declining phase

- Coronal holes, common in the declining phase, bring high speed streams
  - *High speed streams enhance the outer zone MeV electron population, leading to enhanced internal charging hazard to satellites*
  - *Associated high-intensity, long-duration continuous auroral activity (HILDCAA) also leads to many substorms and energetic plasma injections, leading to surface charging hazards to satellites*

BACKUPS

Abstract

Solar maximum is characterized by sunspots, active regions, and eruptions, and the coronal mass ejections, solar energetic particle events and large magnetic storms that follow. The declining phase of the solar cycle typically sees a winding down of these CMEs and large magnetic storms. However, the coronal holes common to the declining phase produce routine, persistent, and recurrent high-speed streams which lead to space weather patterns at Earth that can be as hazardous to satellites as the eruptive transients. Long periods of elevated solar wind speed can lead to extreme conditions in the magnetically trapped MeV electron belts, which, in turn, increases the risk of internal charging on satellites. Fluctuations of the interplanetary magnetic field embedded in these high-speed streams drives auroral, substorm, and convection activity that bathes satellites in hot electron plasma capable of charging surfaces. Whereas the peak of the sunspot cycle typically sees enhanced single event effect and event total dose hazards to satellites, during the declining phase the dominant hazard is more often vehicle charging. This talk will illustrate these points through synoptic data sets with extreme cases identified.