Space Environments for Satellite Operations and Design: Overview, Mismatch, and GOES

Paul O'Brien, Joe Mazur, Joe Fennell, Tim Guild

The Aerospace Corporation

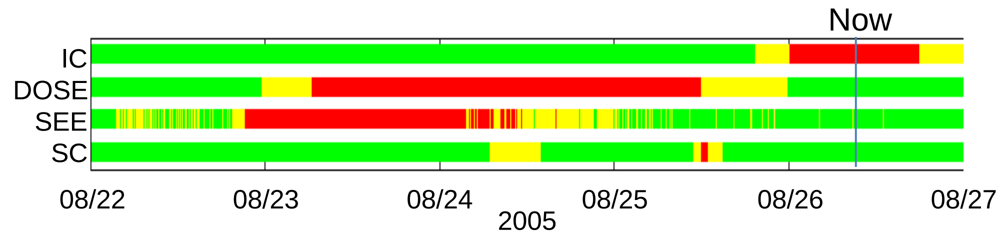
Outline

- Operations Community (Satellite Anomalies)
  – Driven by Forensics
    - Environment at the Spacecraft
    - Mission Context
  – The Mismatch
- Design Community (Design Specifications)
  – Needs Climatology
    - Mean Environments
    - Worst Case Environments
    - Probabilities
    - Space "Climate Change"
  – The Mismatch
- Summary

paul.obrien@aero.org
Space Sciences/SSAL/PSL

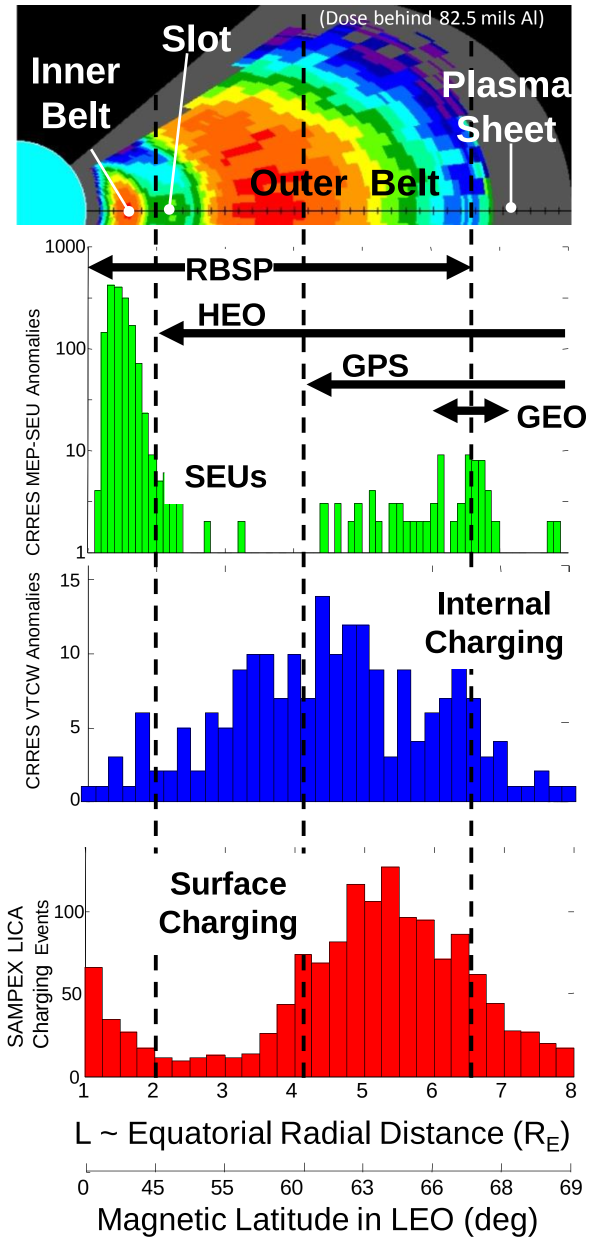
What Do Satellite Operators Want?

- Mostly forensics
  - Satellite anomalies are rare, even under extreme space weather conditions
  - Forecasts provide awareness, but rarely lead to action
- Many do not know what they want
  - They do not have the resources to investigate most of their anomalies
  - If they can recover the system, they may not investigate the cause
- Very few want raw physical quantities (e.g., particle fluxes)
  - Most operators cannot give you a threshold above which they have an anomaly
- Most want a simple indication of what time the hazard is greatest and how that compares to what the vehicle has already seen recently and since launch



paul.obrien@aero.org
Space Sciences/SSAL/PSL

AEROSPACE



What are the Hazards?

- Event Total Dose
  - Caused by ~MeV electrons and multi-MeV protons
  - Driven by flux intensity
  - Requires hours to days of accumulation
  - Typically need evidence on same *L* shell or range of *L* shells
- Single Event Effects
  - Caused by multi-MeV protons and heavy ions
  - Driven by flux intensity
  - Instantaneous
  - Typically need evidence on same *L* shell or range of *L* shells
- Internal Charging
  - Caused by >0.1 MeV electrons
  - Driven mainly by flux intensity
  - Requires hours of accumulation
  - Typically need evidence on same *L* shell or range of *L* shells
- Surface Charging
  - Caused by keV electrons
  - Driven mainly by spectral shape, not flux intensity
  - Usually diagnosed with L, MLT or local temperature/spectrum
  - Timing and location are *hugely* critical

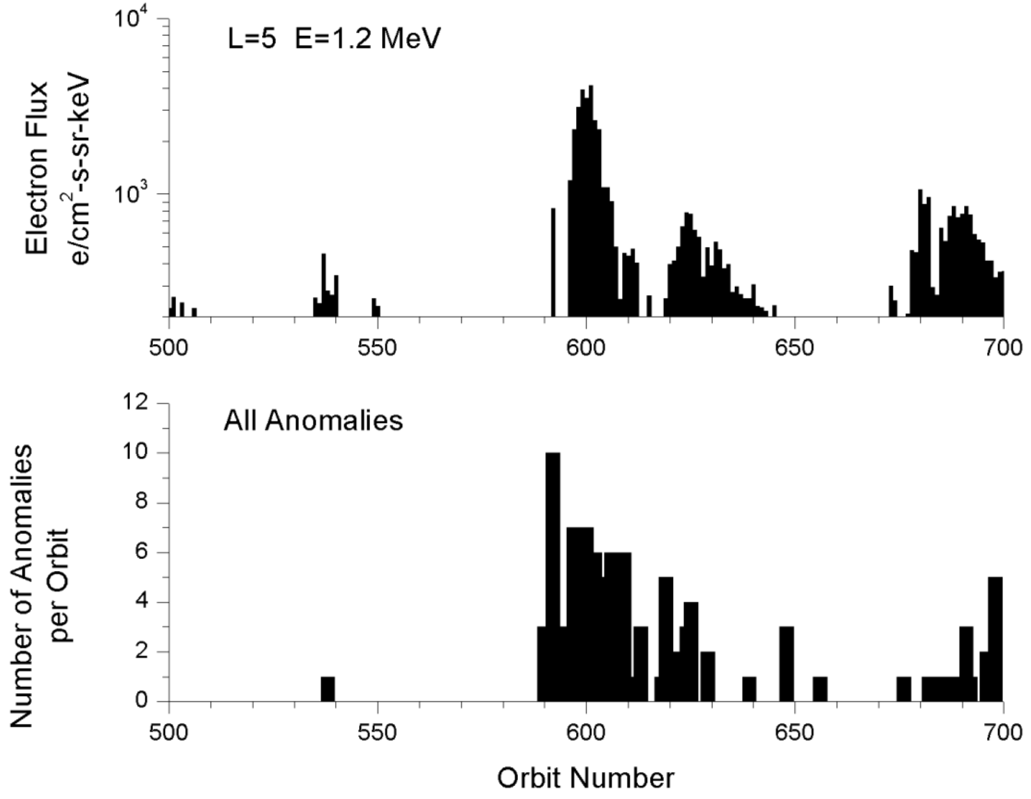
paul.obrien@aero.org
Space Sciences/SSAL/PSL

Location, Location, Location

- The biggest challenge today supporting satellite operators is that they do not have environmental sensors on their vehicles
  - The environment at GOES and POES are not representative of all of geospace
  - Without data, we are left guessing the environment
- Tools for “filling in” the environment everywhere should be a high priority
  - Dynamic geomagnetic cutoff models coupled to L1/GEO fluxes
  - Data assimilation
  - Statistical models driven by data available with low latency (24 hrs)
- Tools to project the 3-D environment onto a satellite orbit

paul.obrien@aero.org
Space Sciences/SSAL/PSL

Mission Context



CRRES Example

- The operator should ask: is the environment at the time of the anomaly worse than other times when there were no anomalies?
- To answer this, we need to know the entire history of the vehicle's environment back to launch

paul.obrien@aero.org
Space Sciences/SSAL/PSL

AEROSPACE

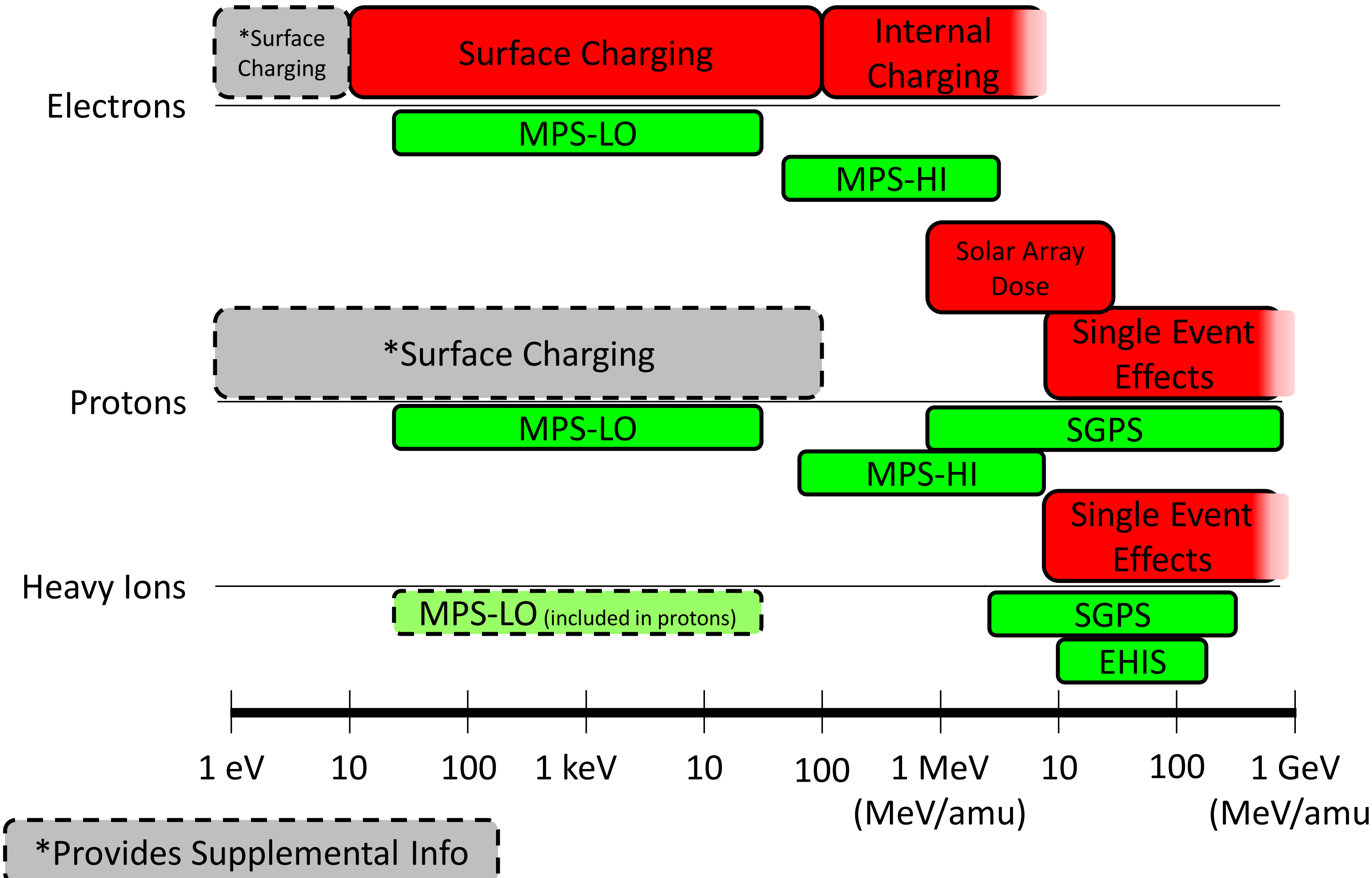
The Magic Numbers

GOES-R

- Provide these top-priority quantities:
  - FAC intensity (LEO) [Surface Charging]
  - Kp [Surface Charging]
  - Electron temperature [Surface Charging]
  - 0.1-2 MeV electron flux [Internal Charging]
  - 20-50 MeV proton flux (heavy ions would be nice, too) [SEE]
  - 1-20 MeV proton flux [Event Total Dose]
- At the operator's spacecraft from near term forecast all the way back to launch
- For forensics, the immediate past (~24 hrs) is the highest priority

paul.obrien@aero.org
Space Sciences/SSAL/PSL

Operational Hazards and GOES-R Measurements



paul.obrien@aero.org
Space Sciences/SSAL/PSL

AEROSPACE

The Mismatch: Operations

- The scientific community is not working on all of these things
  - Until recently electrons were omitted from ring current models
  - Scientists are learning to run MHD models in real time, but not solar particle cutoff models
  - There is little work on statistical models to fill in the 3-D environment on operational timescales
- Why?
  - Most science funding supports curiosity driven research, geared towards understanding the environment
  - The operator community does not typically fund scientists
  - Communication between the scientific and operator communities is very limited:
    - Operators do not attend science meetings or contribute to steering committees
    - Operators cannot always talk openly about their needs

paul.obrien@aero.org
Space Sciences/SSAL/PSL

What do Satellite Designers Want?

Priority	Species	Energy	Location	Sample Period	Effects
1	Protons	>10 MeV (> 80 MeV)	LEO & MEO	Mission	Dose, SEE, DD, nuclear activation
2	Electrons	> 1 MeV	LEO, MEO & GEO	5 min, 1 hr, 1 day, 1 week, & mission	Dose, internal charging
3	Plasma	30 eV – 100 keV (30 eV – 5 keV)	LEO, MEO & GEO	5 min, 1 hr, 1 day, 1 week, & mission	Surface charging & dose
4	Electrons	100 keV – 1 MeV	MEO & GEO	5 min, 1 hr, 1 day, 1 week, & mission	Internal charging, dose
5	Protons	1 MeV – 10 MeV (5 – 10 MeV)	LEO, MEO & GEO	Mission	Dose (e.g. solar cells)

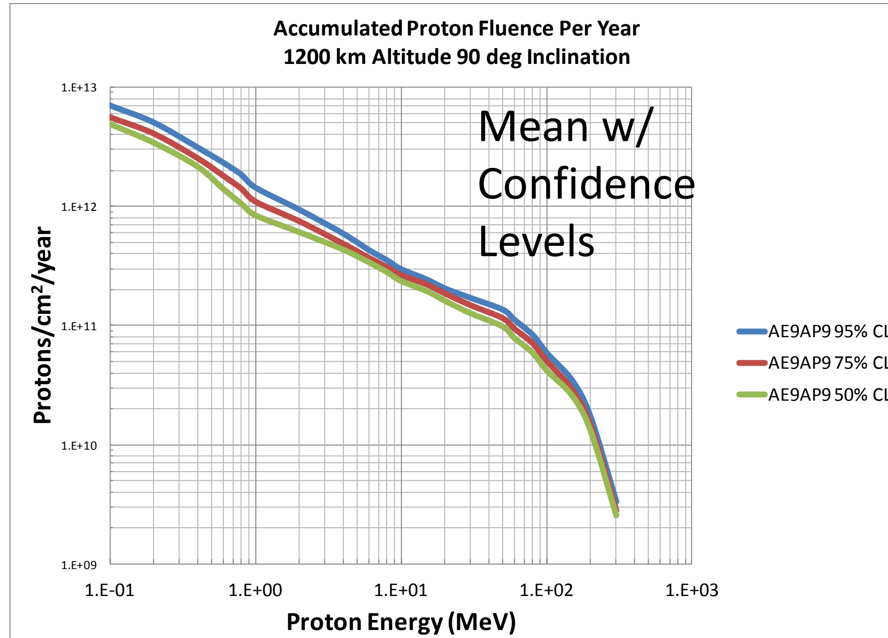
- NASA and the AE9/AP9 team did extensive outreach to obtain this list of requirements
- Notice that it covers everything, everywhere on all timescales
- AE9/AP9 covers this, except Plasma on sub-mission timescales

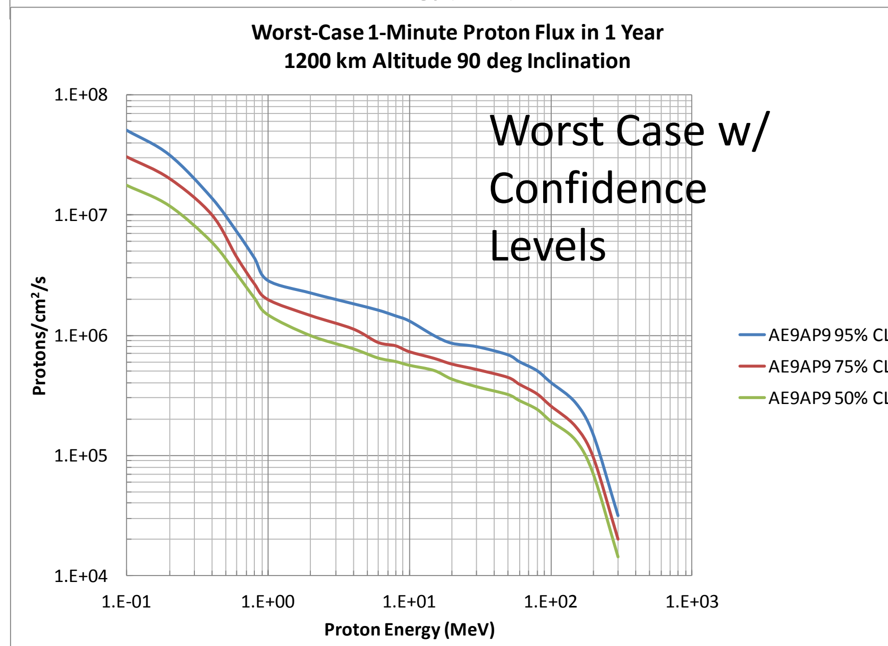
paul.obrien@aero.org
Space Sciences/SSAL/PSL

AEROSPACE

Design Specifications

- Design Specifications are derived from Climatology models
  - Mean environment for arbitrary orbit
  - Worst case environment for arbitrary orbit
  - Confidence intervals to help trade design vs risk
- AE9/AP9 (IRENE) addresses much of this, except surface charging
- Extreme environments *without* probability of occurrence are very hard to use (e.g., superstorms)





paul.obrien@aero.org
Space Sciences/SSAL/PSL

AEROSPACE

Space "Climate Change"

- Will the next solar cycle resemble the last ones, at least statistically?
- This is a critical assumption in the use of all climatology models
- What does it mean for the satellite designer if the next solar cycle is "big" or "small" in sunspot number?

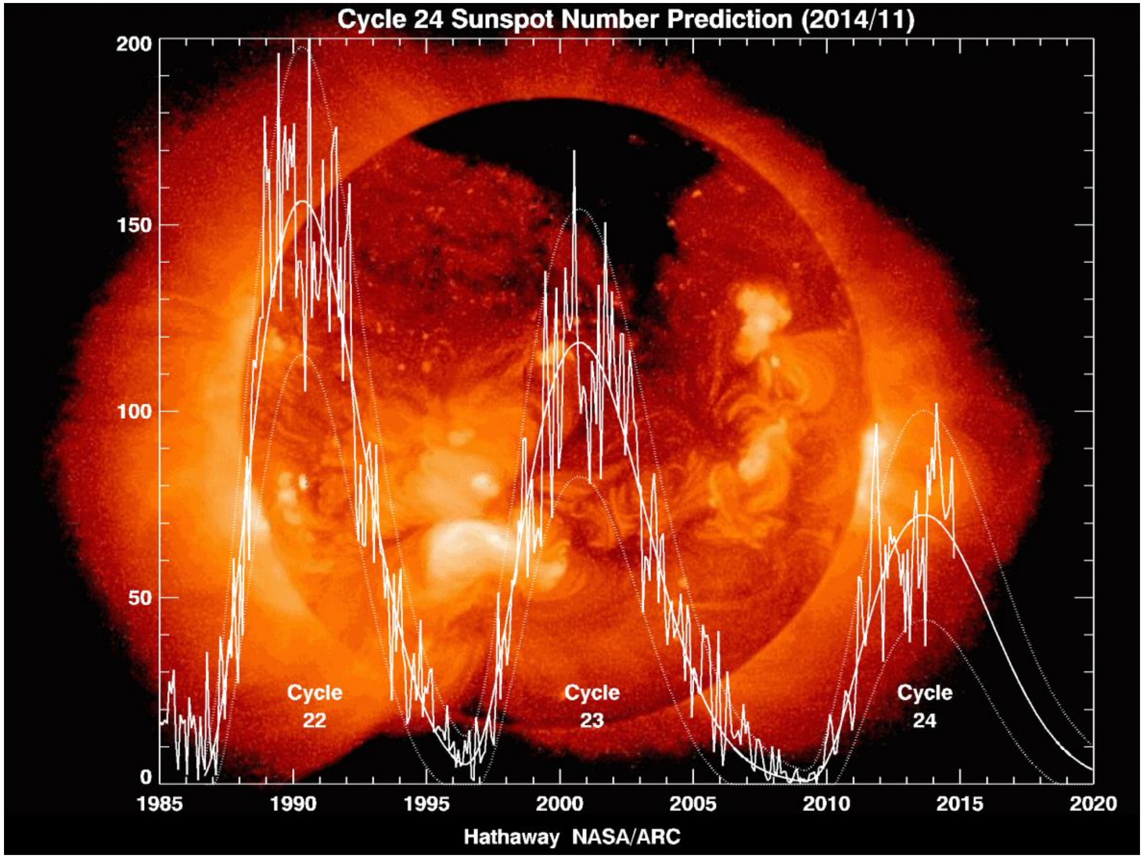


Figure courtesy of NASA/MSFC

paul.obrien@aero.org
Space Sciences/SSAL/PSL

AEROSPACE

The Mismatch: Design

- Still, there is work to do:
  - Extreme events need context:
    - How likely are they over the next couple decades?
    - What are the uncertainties in the extrapolations?
  - Space "Climate Change": Will the next solar cycle match past climatology?
  - Where is the South Atlantic Anomaly going to be in 20 years?
  - Reanalysis Climatology
- The mismatch is not as bad as it is for operations
  - Conscious efforts at outreach by NASA and the AE9/AP9 team
  - Some separate funding: AE9/AP9
  - Satellite design concerns tend to be less *sensitive*, so communication is easier

paul.obrien@aero.org
Space Sciences/SSAL/PSL

GOES Next Measurements

- Particles are a top priority for both anomaly resolution and satellite design
  - The primary hazards to satellites are caused by plasma and radiation particles
  - GOES-R adds energy resolution that permits maximum correlation between environmental measurements and satellite anomalies
- Magnetometer plays a critical supporting role:
  - Detecting magnetic reconfigurations
  - Mapping particle fluxes to other locations
  - Deeper scientific investigations (storm dynamics, wave-particle interactions)
- Example new measurement to consider: GPS occultation to detect plasmapause
  - Plasmapause marks boundary where surface charging is suppressed
  - Plasmapause marks boundary between different physical processes that modify global radiation environment

paul.obrien@aero.org
Space Sciences/SSAL/PSL

AEROSPACE

Conclusion

- The scientific community is doing relatively well supporting the satellite design community, though we could do better
  - Scientific curiosity and understanding happen to match up better
  - There is a focused, funded effort to identify and meet user needs
- We are not doing very well on satellite operations
  - Scientific curiosity and understanding do not match up well with operator needs
  - Funding is narrow or nonexistent: Can/should NOAA solve this?
  - Operators sometimes cannot tell us what they need
    - Don’t know
    - Can’t say

paul.obrien@aero.org
Space Sciences/SSAL/PSL