AFRL Space Environment Research for Ops & Design

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AFRL Research to Ops/Design

The following subset of AFRL’s space environment research efforts illustrates what we identify as bearing on operations and design:

- Characterizing transient environments for anomaly forensics
  - CEASE III, RHAS, REMS
- Nowcasts and forecasts of the environment for operations
  - ADAPT
  - SPE forecasting & mapping
  - GEO flux mapping in LT
- Environment climatology for spacecraft design and mission planning
  - AE9/AP9-IRENE
- Testing and improving designs to minimize vulnerabilities
  - SCICL, spacecraft charging studies
Solar Cell Experiment #1 Results

- Rapid degradation cause for alarm!
- SCREAM w/ CEASE explained results and enabled projections of effects on ops
- Found to result from 1-10 MeV slot protons

CEASE-3

- Anomaly assessments often require local environment data
- Energetic charged particle sensors will need to be carried on new AF satellites
- CEASE-3 has been designed for this role—
  - Characterize particle hazards driving dose, SEE, internal charging effects
  - Minimize burden on host spacecraft

Size: 11cm x 11cm x 27cm
Mass: 3.9 kg
Power: 8W

4 sensors:
ESA with 4 look directions
3 Silicon charged-particle detectors
Energy range, electrons: 50 eV – 5 MeV
Energy range, protons: 2 MeV – 100 MeV
CEASE-3 Sensor Breakdown

LEPET/MEPET
Two 2-element detector telescopes
Passive collimation
Anti-coincidence logic

MEASURES:
- p+ 2 – 17 MeV
- e- 0.1 - 2 MeV
(combined range)
Fluxes:
- electron = 5.4x10^{10} /cm^2 s MeV
- proton = 4.2x10^7 /cm^2 s MeV

HEPET
5-element, actively-collimated telescope

MEASURES:
- p+ 25 – 100 MeV
- e- 2 - 5 MeV
Fluxes:
- electron = 5.8x10^{10} /cm^2 s MeV
- proton = 2.4x10^4 /cm^2 s MeV

IMPROVEMENTS:
- Two additional sensors: ESA, with 4 look directions, and additional particle telescope
- Higher flux ranges and count rates
- Broader energy range with more channels
- Higher reliability instrument – 15 year lifetime
- 2 units currently being developed for 2019 launch
- Design will be transitioned to industry by 2020
Radiation Hazard Awareness Sensor (RHAS)

Mechanical
- 490 grams
- 12.7 cm x 13.7 cm x 2.5 cm External Dimensions
- Al case – serves as camera lid as well as instrument
- Stainless steel lid and spacecraft wall used for differential shielding (mounted inside wall)

Channels:
- Dos1 (54 mils eq. Al) [>1.1 MeV e-, >16 MeV p]
- Dos2 (100 mils eq. Al) [>1.9 MeV e-, >24 MeV p]
- Dos3 (390 mils eq. Al) [>6.0 MeV e-, >47 MeV p]

Diagnostics:
- Temperature monitors (one for each dosimeter)
- On-orbit calibration
- Multiple data acquisition modes

Manifested on 2 identical GEO satellites intended for launch in 2017
Sensor emphasizes SWAP and cost over capability, accuracy, and reliability
REMS Instrument

• REMS is a next generation sensor for space weather monitoring, based on the CERN Timepix chip

• Intended for Small Sat platform

• Developed by Invocon under AFRL sponsored Phase II SBIR

• Sensor chip and software incorporate several advanced features over standard silicon detectors
  – Pixelated detector with 256 x 256 pixels; sensor active area = 2cm²
  – Particle Type discrimination (electrons, protons, helium, heavy ions)
  – Incident angle resolution (over 450 angle bins in a 115° full angle)
  – Energy range: 10 keV to 1 MeV for electrons; 100 keV to 100 MeV for protons
The ADAPT model generates global solar photospheric magnetic field maps.

ADAPT generates 1 to 7 day future forecast maps using flux transport that accounts for known surface flows in the solar photosphere:

- differential rotation, meridional circulation, supergranular diffusion

Global maps are utilized to drive:

- Coronal & solar wind models used to forecast the solar wind and Coronal Mass Ejection (CME) arrival times

- Empirical models to forecast of $F_{10.7}$ and XUV/EUV/FUV irradiance 1 to 7 days in advance for thermospheric modeling

$$F_{\text{model}} = m_0 + m_1 S_P + m_2 S_A$$
Developing a three-step SEP forecasting system to be used to supply solar input to a spacecraft radiation environment model (spacecraft charging, SEUs):

1. **Before any solar event**: Early (next 24 hours) SEP event probability forecast based on Falconer’s “free-energy proxy” tool (used by NASA/SRAG)

2. **Once a solar flare (M2) occurs**: Multi-stage flare-based dynamic SEP event forecast initialized using AF/NOAA (Balch) database of GOES X-ray and SEP events. This forecast then needs to be “aged” as time passes (developed by Kahler et al 2015) depending on flare location.

3. **At SEP onset**: Dynamic forecast of expected peak intensity, spectrum and timescale (under development).

System is completely automated using publicly-available real-time datasets.

- Objective: develop magnetic mapping and apply to SEP observations, yielding real-time estimate of solar proton fluxes at any location in Geospace
- Currently developing and testing alternate approaches to mapping including (if appropriate) determination of magnetic cutoffs
GEO flux mapping in LT

- Model for predicting >2 MeV electron fluxes throughout GEO ring based on GOES data
  - Parameterized by Kp and local time
  - Optimally uses last 6 hrs of GOES data
- Tests from 1998-2009 GOES data yield PE>0.6 in 68% of cases, PE>0.8 in 24% of cases

AE9/AP9-IRENE

- AE9/AP9/SPM specifies the natural trapped radiation environment for satellite design and mission planning, supporting all orbits with statistics for confidence intervals.

- Applications:
  - Spacecraft design
    - Directional flux considerations e.g. for ISS
    - Considerations for extended delivery legs
  - Mission planning (e.g. orbit selection)

- Development needs:
  - Models and model products (SEPs, solar cycle reanalysis, LEO/loss cone gradients, …)
Spacecraft Charging and Instrument Calibration Lab (SCICL)

SCICL—a one-stop shop for detailed spacecraft charging studies
- Mumbo and Jumbo large vacuum chambers
  - Simulation of electron, photon, ion fluxes
  - Sensor calibration
- Support facilities including bell jar, electronics lab, and
- Class 1000 Clean Room
  - Dry box storage for flight hardware

- Component testing in flight-like conditions
- Material aging
- Surface/internal charging testing
  - ISO 11221
Spacecraft Charging Studies

- Balance between input/output charge fluxes yields **Frame Potential** for spacecraft as a whole and **Differential Potentials** for individual dielectric surfaces.
- **Differential potentials** between conductors and dielectrics lead to *high electric fields* and *arcing* - material breakdown (deep-dielectric discharge), surface vacuum arcs, or catastrophic *sustained arcs*.

- Identified two populations of sustained solar array arcing events in commercial GEO satellites—one from severe charging LT environment, one from eclipse entry/exit.


- Led round-robin testing determining that durations of arcing events are driven by multiple plasma species.


- Preliminary positive results using Arecibo to detect arcing in GPS solar arrays.

AFRL’s applied space environment research covers the range from the nature of geospace hazards to how designers and operators can cope with them

- Forecasting and nowcasting of particle hazards
- Climatology models for design
- Hazard mitigation technology
- Design standards
- Materials testing
- Compact sensors for anomaly assessment