Energetic Particle Sensors for Anomaly Attribution and Environmental Specification (CEASE & RHAS)

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Motivation

**Current Approach:**

1. **Design for Robustness**
   - Designs and components have heritage and/or testing to env. specifications
   - Requires good environmental models – what do we design to?

   Most of the time this works, but occasionally the space particle environment still causes anomalies

   **First time occurrences**

2. **Anomaly Attribution**
   - Isolate anomaly to particular subsystem
   - Determine source of anomaly based on understanding of subsystem that is affected
   - **Particle environment is often not considered until source of last resort**

3. **Impact to Operations & Mitigation**
   - Accurate knowledge of cause enables best assessment and mitigation strategy

   **Can be time critical!**

Often we don’t have actionable data on the particle environment
What is a “good” energetic particle sensor for anomaly attribution?

AFRL among the first to attempt to answer this with the Compact Environmental Anomaly Sensor (CEASE) developed in mid-1990’s:

Size, weight, and power (SWAP)  
Cost  
Capability (Particle Species, Energetic Coverage, & Channels)  

Effort focused to a large extent on finding right mix of these quantities

Experience with CEASE has shown importance of other issues:

Ease of data interpretation/logistics – How easy is it to process its data, relate it to anomalies, and get the right information in the decision maker’s hands?

Accuracy and reliability – Can the data be trusted when its most needed?

Range of operating environments – Can the instrument work over a wide variety of conditions?

Data can also be used to improve environmental specifications
Compact Environmental Anomaly Sensor (CEASE)

Particle Detectors
- 2 Dosimeters (Heavy and Light Shielded)
- Two element particle telescope
- SEE sensor
- Nominally 1-80 MeV protons, 0.05-3 MeV e⁻
- CEASE II adds electrostatic analyzer for low energy electrons

Vital Statistics
- Mass: 1 kg
- Power: 1.2 W
- Size: 10 x 10 x 8 cm

CEASE Instrument Functions
- Provide real-time warning of space environmental hazards
- Assist satellite operators in investigating anomalies
- If spacecraft resources allow, collect detailed radiation environment data for research and input to specification and forecast models
## CEASE Flight History

<table>
<thead>
<tr>
<th>Mission</th>
<th>Orbit</th>
<th>Launch</th>
<th>Status</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>TSX-5</td>
<td>LEO (410 x 1710 km, 69° inc)</td>
<td>Jun 2000</td>
<td>Ended in 2006</td>
<td>B.K. Dichter et. al demonstrated excellent correlation between SEE type anomalies and CEASE data; Data has been extensively used in AE9/AP9 v1.0.</td>
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<tr>
<td>DSP-21</td>
<td>GEO</td>
<td>Aug 2001</td>
<td>10+ years in operation</td>
<td>First CEASE II with electrostatic analyzer; Used in AE9/AP9 validation</td>
</tr>
<tr>
<td>SES-12</td>
<td>GEO</td>
<td>Activated Jun 2010</td>
<td>Operational CEASE II</td>
<td>First commercial operation of CEASE</td>
</tr>
<tr>
<td>TACSAT-4</td>
<td>HEO (700 x 12050 km, 63°)</td>
<td>Sep 2011</td>
<td>Completed mission in 2013</td>
<td>Identified elevated proton levels responsible for accelerated solar degradation; Proton data is one of key upgrades in AP9 v1.2</td>
</tr>
<tr>
<td>DSX</td>
<td>MEO (6000 x 12000 km, 45° inc)</td>
<td>Late 2015</td>
<td>CEASE I Integrated</td>
<td>Final CEASE I unit will be part of comprehensive science suite to measure MEO particle populations</td>
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Extensive flight history has provided AFRL and its partners with a unique perspective

TACSAT-4 in particular is an important example of anomaly attribution
TACSat-4 Solar Cell Degradation
(Effects of 1-10 MeV Slot Protons)

Solar Cell Experiment #1 Results

- Rapid degradation cause for alarm!
- SCREAM w/CEASE explained results and enabled projections of effects on ops

Lines: SCREAM w/ CEASE
Data: SCE #1

Mission planned using AP8min

Power Array: Emcore ATJ (3J) w/ 6 mil CMG coverglass (current at load only)

SCE #1: Emcore BTJM (3J) 3-cell string w/ 6 mil CMG coverglass (full IV curves)

1. P.P Jenkins et al., “TACSat-4 Solar Cell Experiment: Two Years in Orbit.”
10th European Space Power Conference, Noordwijkerhout, NL, 14 Apr 2014.
Timeline Showing Challenges of Attribution

**Launch**

- **Sep. 2011**: AFRL notices apparent enhanced proton flux at L~2.5-3.1 but questions exist because CEASE response historically was not trusted below proton energies of 15 MeV. NRL operations team notified about this finding.

- **Oct. 2011**: NRL SCE scientists contact AFRL with questions about environment. Crash effort begun to provide proton spectra required to drive SCREAM.

- **Nov. 2011**: Initial results from CEASE proton spectra appear promising. However, a new problem appears of a strong dropout in proton fluence. Speculation is it is associated with sensor look direction.

- **Dec.-Jan. 2011**: Speculation that dip is associated with look direction is confirmed. AFRL unfolds effects of look direction on fluence spectra and first quantitative estimates show good agreement with SCE #1.

- **Feb.-June 2012**: TACSAT-4 operations begins limited usage of SCREAM/CEASE results to estimate potential impact on future operations. Results are first presented to community at NSREC.

- **Sep. 2012**: TACSAT-4 successfully ends its mission after 2 years on orbit.

- **Sep. 2013**: AP9 version 1.2 released with fully cleaned and cross-calibrated CEASE data from TACSAT-4 among improvements.

What have we learned from this experience about what makes a good energetic particle sensor for anomaly attribution?
Importance of Accuracy & Reliability of Particle Data

**CEASE response for 1-10 MeV protons**

- Biggest factor in slowing down confidence in attribution analysis
- Understand limitations of the sensor (models and calibrations critical to achieving this)

**Significant concerns existed about CEASE’s ability to measure 1-10 MeV protons**

- CEASE observes counts
- Response
- Proton flux

\[ C_i = \int_0^\infty G(E) j_{iso}(E) dE \]

CEASE channels at these energies required careful analysis since they respond most strongly to high energy protons

**Cross-calibration with ACE/GOES**

Ultimately, excellent performance achieved for soft spectra
NRL’s SCREAM (Solar Cell Radiation Environment Analysis Models) required spectra to do assessment

- Understand what is required to drive attribution software from sensor
- Be able to quickly generate particle spectra as it is the basis for most advanced analysis

Problems existed in initially getting attitude data but ultimately proved critical in analysis

- Information flow both from and to the spacecraft operations center is critical to performing timely anomaly attribution

Proton flux during 0.5°/s roll
Focus has been on extending CEASE capabilities, accuracy, and reliability – not reducing SWAP and risk reduction unit’s first planned flight is to GEO in 2017 (delivery early 2016)
Example of Anticipated Improvements Using LEPET

- Out-of-band background due to protons has been significantly decreased (10-100x)
- Much higher resolution channels (10-100x)
- Eliminates 0.2-1 MeV electron response dropout present in existing CEASE design
- Better statistics with larger geometric factor and higher maximum count rates

First flights primary objective is cross calibration with GOES for validation purposes
Radiation Hazard Awareness Sensor (RHAS)

**Mechanical**
- 490 grams
- 5”x5.375”x1” 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 – question is whether the data is sufficient for simple, correlative type anomaly attribution?
Conclusion

Successful use of space particle detectors as hosted payloads for anomaly attribution requires designing sensors with an appropriate balance between:

- Cost
- Size, Weight, and Power
- Capability
- Establishing trust in data

These principles as well as experience with CEASE I & II are guiding the development of AFRL’s CEASE RR/III and RHAS sensors.