CubeSats and Radiation Damage

Spectral Ocean Color Imager (SPOC) and Multi-view Onboard Computational Imager (MOCI)

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Overview

Neither the inner nor the outer Van Allen belt would initially appear to be of great consequence to a satellite in low Earth orbit, because of the high altitudes at which they reside. However, the weakness of Earth's magnetic field at its intersection with Earth's rotational axis permits the lower belt to penetrate the atmosphere to as low as 200 kilometers. This is the South Atlantic Anomaly. This region consistently exposes satellites in low Earth orbit to high levels of energetic charged particle flux. Almost every satellite passing through the SAA at altitudes between 100 and 1000 km has suffered some kind of damage or degradation to its equipment or performance. CubeSats especially are subject to hazard, not least because they are so often constructed with off-the-shelf parts, which are not usually designed to withstand the radiation environment of the SAA. SPOC's and MOCI's altitude and inclination are such that it will possibly pass through the South Atlantic Anomaly in excess of four or five times a day.

Radiation Environment and Modeling

The three main contributors to SAA radiation are the Van Allen belts, galactic cosmic radiation, and solar energetic particles. Over 4-5 decades, several empirical models of SAA particle flux have been developed, among which values for a given location can vary by several orders of magnitude. The lack of recent, accurate data on the radiation environment within the SAA can be a sticking point for related predictions and precautions. Proton radiation poses the greatest threat. Proton flux in the SAA is generally stable, but measurement is complicated by its anisotropy, which compromises the accuracy of cumulative dose predictions based on omnidirectional fluxes.

The NASA-sponsored AP8/AE8 models have been the standard for decades. They consist of omnidirectional arrays of proton and electron flux, which neglect anisotropy. Organized in L-shells of the magnetosphere, they give simple average fluxes of particles of varying energies. In this respect they can be said to lack nuance. The models are static, possibly subject to contamination, and are significantly limited by their underestimation of dosage at altitudes between about 6000 and 12000 km. Despite the shortcomings of AP8/AE8, they remain the best available option for SPOC and MOCI''s dosage predictions.

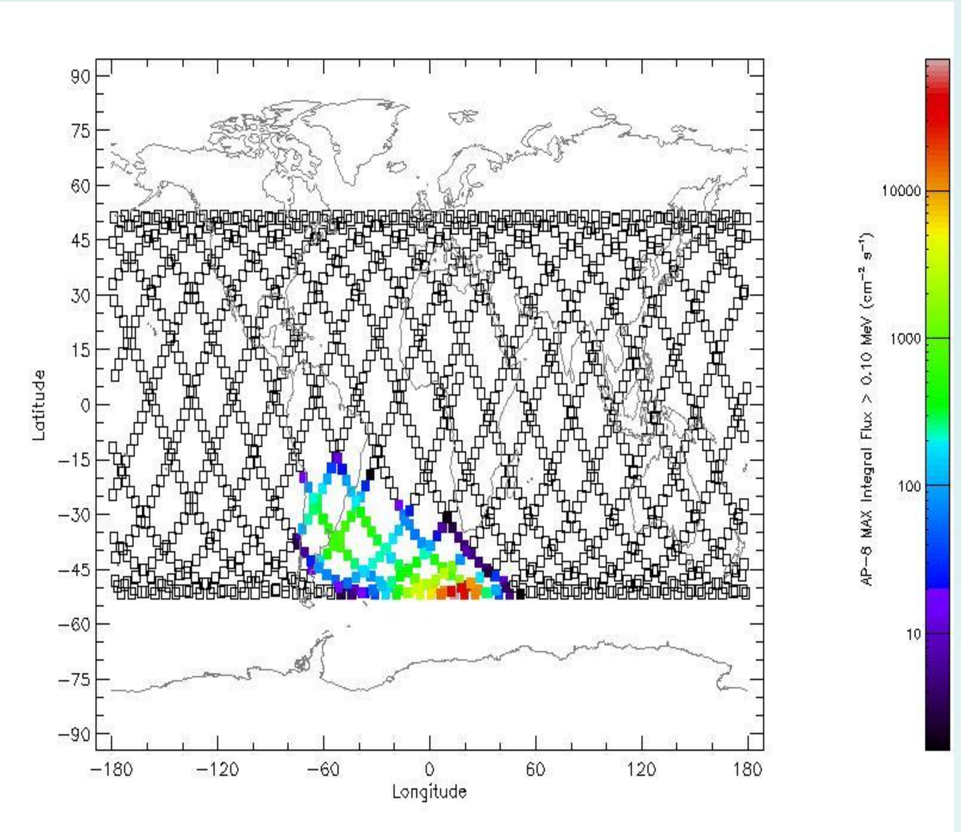

Figure 1: Greatest expected proton radiation exposure occurs in South Atlantic. Courtesy Matt Hevert.

Assessment of Risk to SPOC and MOCI

Simulations were conducted in STK 11. Radiation exposure was computed over 1 year for a satellite of SPOC/MOCI's cross-sectional area, following an orbit based on that of the International Space Station.

The selected magnetic field configuration was IGRF Olson-Pfitzer. This model is accurate without sacrificing computational speed.

From a list of computational radiation modes, the NASA mode was selected. NASA mode uses the standard AP8/AE8 models.

It was concluded that SPOC and MOCI should travel through the South Atlantic Anomaly well over 1000 times in a year.

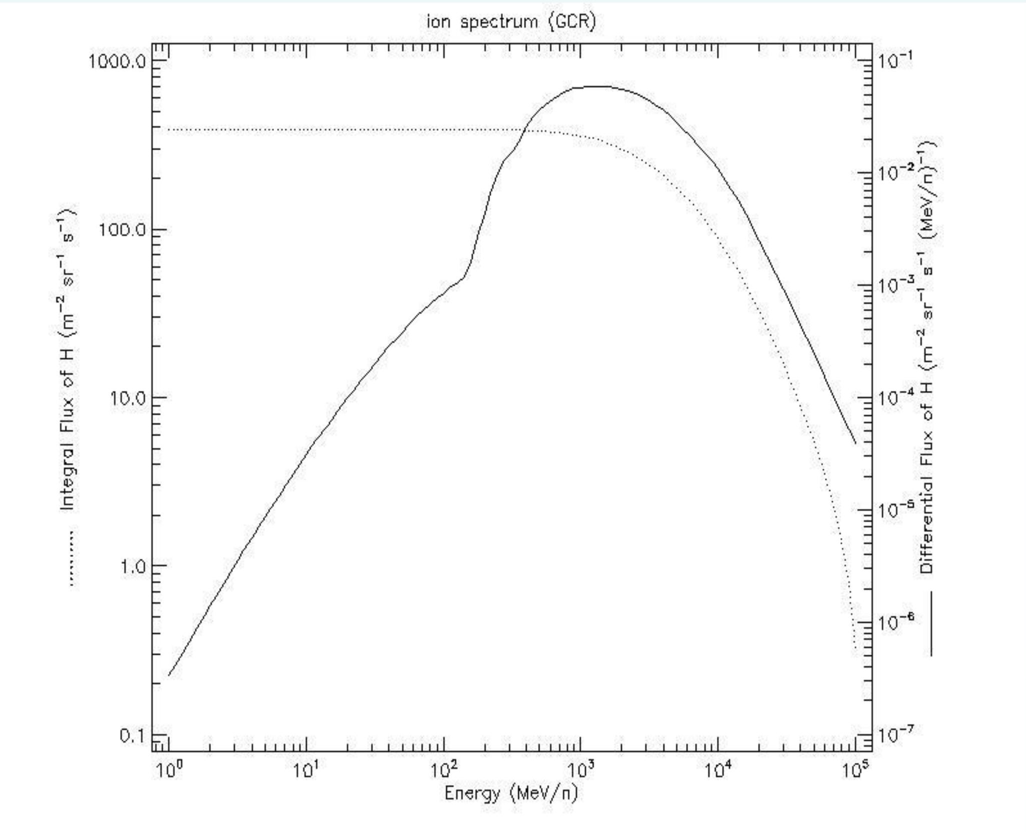

Figure 2: Illustrates radiation specifically due to galactic cosmic radiation background, as opposed to solar energetic particles or Van Allen belts. Courtesy Matt Hevert.

Cumulative radiation exposure is largely unpreventable, but the nature of CubeSat design implies a short lifespan, and it was found that not many long-term effects should become apparent while the mission is active. Cumulative dose is represented in the graph in Figure 2.

The threat to SPOC is largely posed by the risk of Single-Event Effects, such as stuck bits, gate ruptures, and Single-Event Latchups (SELs), which can easily be mission-fatal. Thus, most recommendations are focused on preventing SEEs.

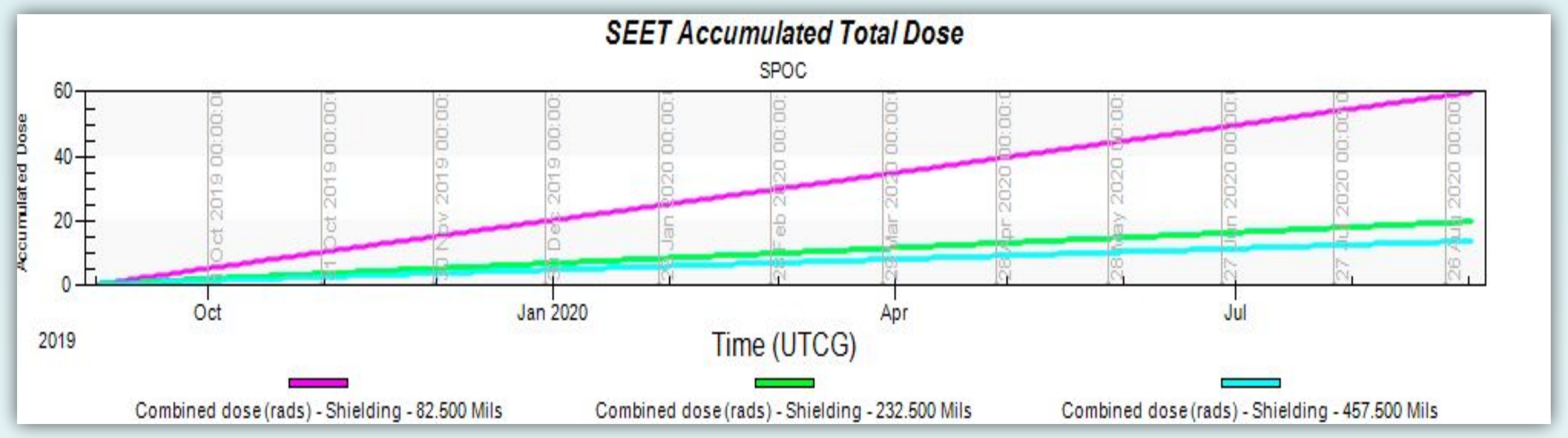

Figure 3: Shows steady increase of cumulative dose over 1 year.

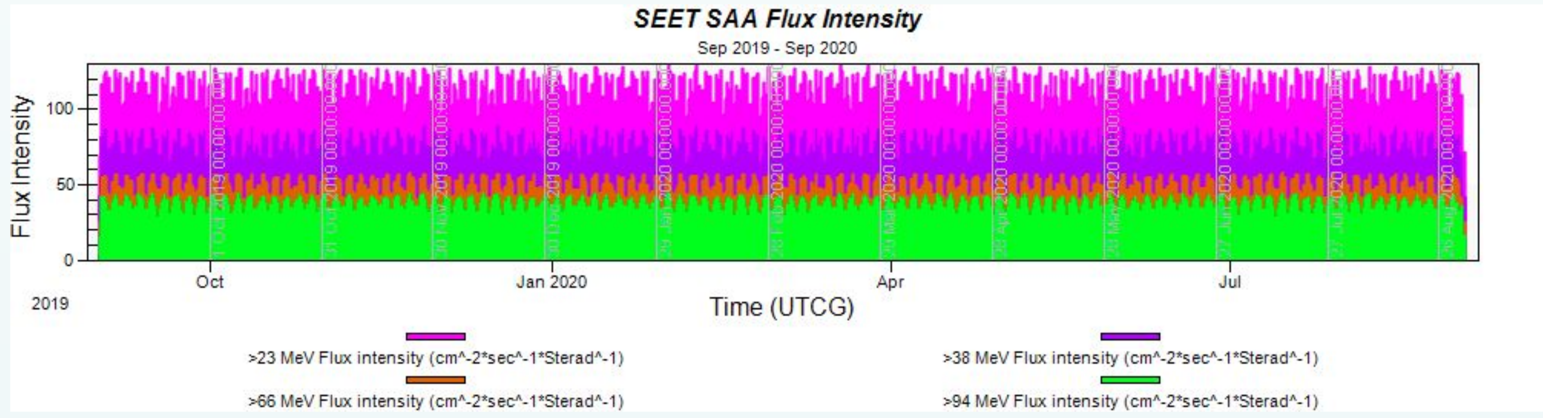

Figure 4: Flux intensity for various energies within SAA

Precautions and Mitigation

For any component or procedure that fails, there should, if possible, be another component or procedure which fulfills an equivalent function.

One protective measure against SEEs is to cease all unnecessary operation while in the SAA. Additionally, it is sometimes possible to restore the integrity of data or functionality of equipment compromised by SEEs. For example, error correction codes (i.e., Reed Solomon codes) can be used to correct bit errors in image data.

Vis-à-vis CubeSats, it is important to confirm that all off-the-shelf components advertised as radiation-hardened are in fact hardened to the purported extent.

Going forward, it would be wise to examine radiation exposure using models besides the standard AP8/AE8 and compare results, even given the considerable shortcomings of some of the other empirical models. CRRESPRO, for example, covers a narrower area, but uses more recent data. If possible, we would be interested in mounting some kind of radiation gauge to SPOC and MOCI in order to contribute new data for modeling the SAA environment.

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