Monitoring Space Radiation Hazards with the Responsive Environmental Assessment Commercially Hosted (REACH) Project

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34-WORD ABSTRACT
We present new results from space weather monitors that are being deployed in a low-Earth orbit satellite constellation. The REACH project will provide unprecedented near-real-time measurements of total dose, spacecraft charging, and single-event effects.

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Introduction

The Responsive Environmental Assessment Commercial Hosting (REACH) project uses radiation dosimeters on a commercial satellite constellation in low Earth orbit to provide unprecedented spatial and time sampling of space weather radiation hazards. The spatial and time scales of natural space radiation environments coupled with constraints for the hosting accommodation drove the instrumentation requirements and the plan for the final orbital constellation. The project has delivered a total of 32 radiation dosimeter instruments for launch with each instrument containing two dosimeters with different passive shielding and electronic thresholds to address proton-induced single-event effects, vehicle charging, and total ionizing dose. There are two REACH instruments currently operating with four more planned for launch by the time of the 2017 NSREC meeting. Our aim is to field a long-lived system of highly-capable radiation detectors to monitor the hazards of single-event effects, total ionizing dose, and spacecraft charging with maximized spatial coverage and with minimal time latency. We combined a robust detection technology with a commercial satellite hosting to produce a new demonstration for satellite situational awareness and for other engineering and science applications.

Investigation context

Single-event effects (SEE), total radiation dose, and satellite charging (commonly categorized as surface and internal charging) are the primary radiation hazards for satellite design and operation. Prior studies of on-orbit anomalies have shown that these effects as the most commonly attributed space radiation impacts to satellites (e.g. Koons et al. 1999; Ecoffet 2013). Satellite design specifications routinely include these hazards as well as others in the space environment (orbital debris; micrometeroids; signal transmission through the ionosphere and troposphere; and atomic oxygen in low-Earth orbit). Our primary interest in the REACH project is to demonstrate a way to monitor the always-present radiation effects at satellites. We traded physical resources available for the REACH hosted payload and the constraints of available technology and cost as we designed the project and its implementation.

The REACH project has similar goals to other concepts of distributed space weather monitors. One attribute common to satellite-based environmental monitoring is that making any measurements from space involves challenges for cost and operations, especially if the mission requires the return of data from all of the space-network nodes. The appeal of distributed satellite measurements nonetheless continues to drive concepts for ways to reduce cost. The cubesat platform is one approach for satisfying science questions where "high-cadence or multipoint measurements are essential for studying highly coupled systems" (NAS SSB 2016).

Investigation Approach

Figure 1 is the operational view of the REACH project. The REACH hosts are commercial satellites in polar low-Earth orbit (LEO). We are exploiting the ability of polar LEO satellites to sample a wide range of magnetic field lines per orbit (e.g. Kanekal et al. 2001) in order to maximize the revisit time for as many trapped and precipitating particle populations as possible. We are also addressing the latency issue by using the host's in-space communications network to retrive the data from all REACH instruments. Figure 1 uses examples of space hazard measurements and associated anomalies from the SAMPEX mission [Baker 1992], including SEE (Seidleck et al. 1995) and surface charging anomalies (Mazur et al. 2011) observed on SAMPEX. Missions like SAMPEX, with measurements of the charged particle hazards as well as anomalies on the same vehicle, not only illustrated the spatial correlation of anomalies with specific trapped radiation regions but also provided metrics for required revisit and dwell times for REACH.

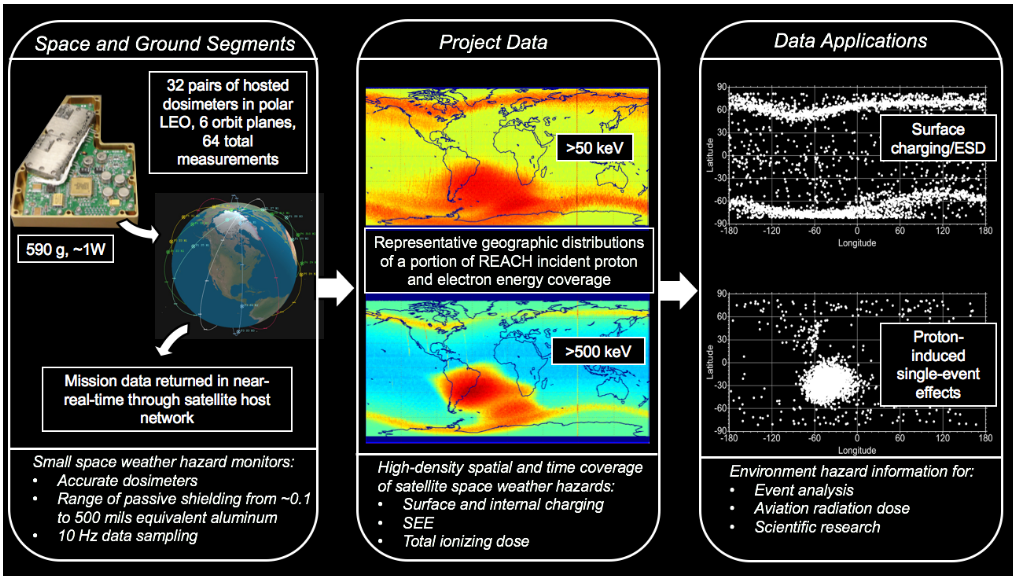

Figure 1. REACH operational view. The space segment consists of hosted pairs of dosimeters whose data flow through the in-space satellite network for ground processing. The project data are dose rates sampled from 32 separate satellites with a wide range of equivalent shielding for engineering and scientific applications. Enivronment and spacecraft effects examples are from the SAMPEX mission.

The REACH project uses a commercial hosting will ultimately include measurements from 6 polar orbital planes at nominal 760 km altitude. Satellite cross-links allow us to meet REACH time sampling requirements with only the cost of data transfer and not the costs of new ground terminals.

Figure 2 shows the REACH flight hardware concept and implementation. Each of the REACH instruments, called pods, contains two dosimeters. We chose the Teledyne microdosimeter for the detecting technology because of our flight experience with these dosimeters, the quality control derived from large-scale manufactring, their performance, and their cost. We added a new dosimeter design that is planned for manufacture to allow for detection of electrons at 50 keV in 6 of the pods. The relatively minimal hosting accommodations immediately constrained what we could use for particle detection. We worked within these constraints to create a well-defined mass distribution of shielding in front of and surrounding the dosimeter detectors.

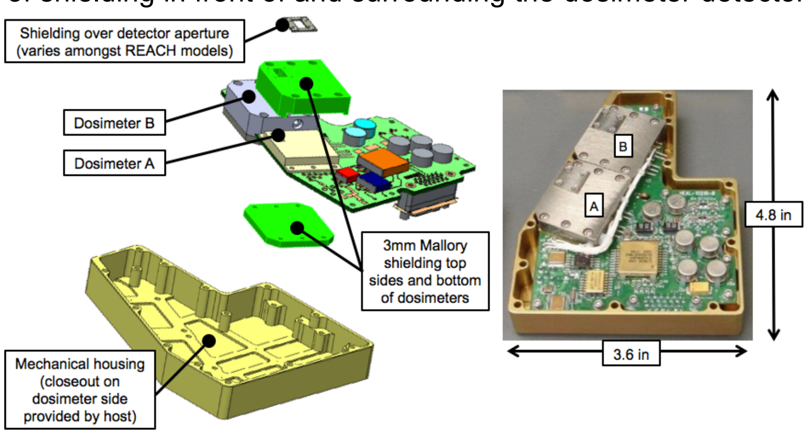

Figure 2. Expanded view of the primary REACH pod components: mechanical housing; single printed circuit board with interface circuits and circuitry for buffering and packetizing of telemetry; dosimeter detectors and their shielding. The photo on the right shows the pre-integration configuration of a Model 3 pod with outer dimensions. The labels A and B correspond to dosimeter identifications in the REACH telemetry.

REACH incorporates dosimeters for its mission, but they are more accurately considered as single-element particle detectors with integral energy response. Every REACH dosimeter has been calibrated for dose in its detector volume, yet the variety of energy deposit thresholds, shielding, and careful consideration of particle access produce more capable measurements of the external proton and electron environments than the use of dosimeters might suggest. In addition, one variant of REACH instrument (Model-1) includes a high-linear-energy transfer dosimeter (energy deposit threshold ~1 MeV) to contribute to proton/electron discrimination. Table 1 lists the pod models, their shielding, and approximate energy thresholds for detection of protons and electrons. The 3mm of Mallory that encapsulates each Teledyne dosimeter minimizes the contribution of out-of-view protons and electrons in the dose rates by increasing the effective shielding for particles that penetrate the sides and back of the REACH pod. The approximate energy thresholds for side or back penetration are >90 MeV and >13 MeV for protons and electrons, respectively. We sample the dosimeters at 10Hz frequency and include sensor voltages and a temperature measurement in the telemetry. REACH produces data packets once per second with a total telemetry rate of 288 bits per second per pod.

We chose the distribution of total number of the various pod models to give higher weight to the lowest-energy electron measurements because the higher time-variability of electron environment, while keeping in mind that we wanted to monitor the solar proton cutoff latitudes at many local times for SEE considerations during solar energetic particle events (e.g. Leske et al. 2001). This led to an approximate 40% - 22% -16% distribution of Models 1, 2, and 3 respectively in the final population of 32 pods. Model-0 development and integration became possible later in the project because of interest in extending the lower-energy range for electrons to ~50 keV in order to measure a portion of the electron environment that contributes to satellite surface charging. The number of Model-0 pods flowed from observed surface charging anomalies on the SAMPEX satellite, leading to a minimum of 4 measurements in a given orbital plane. Additional coverage of other local times would have been ideal but the development and integration schedule restricted us to plan to populate only two orbital planes with Model-0 pods.

Model number	Total number of each Model	Dosimeter A				Dosimeter B			
		Detector shielding[1] (mils equivalent aluminum)	Electronic threshold[2]	Incident proton energy[3]	Incident electron energy[4]	Detector shielding[1] (mils equivalent aluminum)	Electronic threshold[2]	Incident proton energy[3]	Incident electron energy[4]
0	6	32	0.1	11.7	0.36	0.1	0.03	0.2	0.05
1	14	32	0.1	11.7	0.36	32	1.0	11.7	No sensitivity[5]
2	7	183	0.1	31.1	1.60	383	0.1	47.3	3.41
3	5	183	0.1	31.1	1.60	533	0.1	57.1	4.97

Notes:
1. Shielding directly over 3mm x 7mm detector location. Other access paths shielded by the equivalent of ~1000 mils.
2. Refers to the approximate energy deposit (MeV) in dosimeter detector to trigger a single dose count equivalent to ~10 μrads.
3. Proton energy (MeV) required for normal incidence through detector-only shielding.
4. Continuous slowing down approximation electron energy (MeV) for normal incidence through detector-only shielding (assumed to be tungsten for this calculation)
5. High-LET threshold eliminates electron deposits from the dose measurement.

Table 1. Summary of the REACH pod shielding, electronic, and particle energy thresholds for the four model types.

First Results and Project Status

The first three REACH pods have been on orbit since late January 2017. Two are currently operating and the third from the first launch set will become operational in 2018. We have verified the data flow from space to ground of the two operating pods and have been routinely processing the dosimeter data from counts to geo-registered dose rates. Figure 3 is an example of the measurements from a Model-1 pod with geo-located averaged dose rates from ~20 days in April to May 2017. The figure also shows 30-second averaged rates for approximately one orbit where the effect of the high-LET threshold in Dosimeter-B reveals information about the LET spectrum in the inner proton belt and eliminates contributions from electrons in the outer radiation belt.

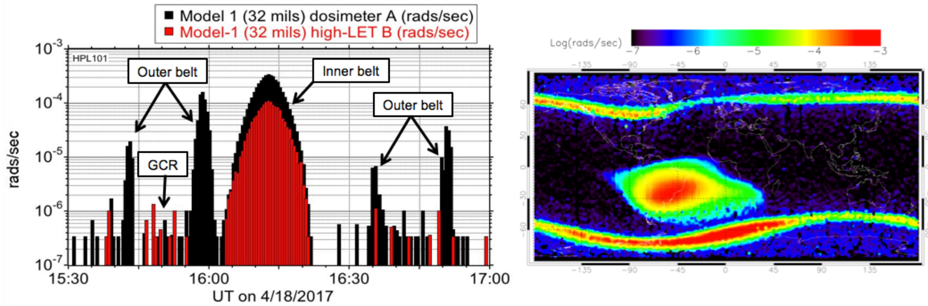

Figure 3. Example of one orbit of averaged dose measurements with a Model-1 REACH pod, dosimeter-A (32 mils shielding, 0.1 MeV electronic threshold, >11.7 MeV protons and >0.36 MeV electrons). GCR refers to the low dose rate from galactic cosmic ray protons at high polar latitude. The rightmost image is the Dosimeter-A rate averaged from mid-April to mid-May 2017

All REACH data are processed to create daily netCDF files with 0.1-second resolution dose rates and geographic and geomagnetic ephemeris at 1-second resolution. By the time of the 2017 NSREC meeting we expect that 4 more pods will be on-orbit. Having as many as 6 operating pods would be comparable to the NOAA/POES constellation at times in the past decade. In the case of REACH, all the data are available from every measurement location in near-real-time. Future launches will fill out the orbital plan to provide an unprecedented capability for space radiation hazard monitoring and for other science and engineering applications.

Summary

REACH will provide unprecedented time and spatial coverage of single-event effects, total radiation dose, and satellite charging hazards. The first REACH pods launched in early 2017 and and the space-to-ground data architecture have demonstrated that the full 32-pod mission concept will achieve its objectives.

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