UK Space Environment Impacts Expert Group

Comments on US Space Weather Benchmarks for ionising radiation

Complied by mike.hapgood@stfc.ac.uk, 20 March 2017

Introduction

This document consolidates comments from the UK Space Environment Impacts Expert Group (SEIEG, a group of independent UK space weather experts set up in 2010, with the encouragement of Cabinet Office, to provide advice to UK Government bodies seeking to mitigate the risks posed by space weather). It provides comments on the "Space Weather 1 Phase 1 Benchmarks" produced by the Space Weather Operations, Research, And Mitigation Subcommittee of the US National Science and Technology Council.

This document contains comments on the benchmarks for Ionizing Radiation

1 Overview

This section has a significant amount of material, giving a broad review of the topic, especially for particle energies that affect satellites. In this format it may be useful for scientists who seek a review of the topic or for satellite effects engineers who will know how to extract relevant information. But it lacks a focus that will aid the broader community interested in space weather and its adverse impacts. They need a better focus how environment and impacts are linked – so the benchmarks have a clear purpose. This is a good example of why we consider that iteration between scientists and engineers is essential to the assessment of space weather extremes.

In the rest of this section we first highlight atmospheric radiation as a critical space weather environment that needs much better treatment in the benchmarks. We then provide a number of specific comments homing-in on details that concern us.

2 Atmospheric radiation

The report does not cover atmospheric radiation environments in any detail. But this is a very important area of space weather impacts in particular for single event effects in avionics such as engine and other control systems. Human radiation dose is also a consideration but perhaps less critical as it does not lead to immediate danger. However, some countries have regulatory requirements on aircrew exposure, creating a demand to monitor how that individual aircrew exposure evolves over time. Following an extreme event there would undoubtedly be demands to quantify the exposure of passengers in flight during the event. As far as we know there is currently no model or set of observations that is available, tested, reliable or accepted to quantify exposure during extreme SEP events (as opposed to assessment of doses from the background of galactic cosmic rays as they change over the solar cycle).

We strongly recommend that the benchmarks are expanded to include atmospheric radiation – reflecting the importance of this area, e.g. as demonstrated by the joint US-UK workshop on aviation impacts held in London in October 2014. The benchmarks should follow up on the joint actions following that workshop; we would be happy to help from UK side of those actions. Key issues include:

1. The benchmarks for high-energy SEPs should go to much higher energies to cover the source particles that drive atmospheric radiation events. Ideally up to 20Gev. Figs 3, 5, 6 and 7 in the benchmark document do not go high enough in energy – secondaries from 400 MeV protons and above will reach the aircraft and the ground at high latitudes during an SEP event.
2. The benchmarks should utilise data from ground based neutron monitors to define hard spectrum events, including data from the 1956 event as the observed worst case. The proxy data for the 774AD should also be considered along with other data on cosmogenic nuclides.
3. Space tourism (i.e. sub-orbital flights such as Virgin Galactic) also need to be considered in setting the benchmarks for atmospheric radiation. At the altitudes of these flights enhanced radiation events will comprise a mix of primary radiation (e.g. protons and ions from the Sun) and secondary radiation (e.g. neutrons), leading to a complex modelling challenge.
4. Ground level SEE events are a cause for concern in the UK, e.g. in respect of control systems for many infrastructures, and also the emerging issue of driverless cars. It is not clear that software engineers have considered space radiation in the scenarios used to write risk resilient software.
5. We also recommend to consider how geomagnetic cutoff affects extreme environments in the magnetosphere, not least how these change during a large geomagnetic storm when geomagnetic shielding is reduced.
6. We recommend benchmark actions to encourage more measurements of atmospheric radiation to validate models and improve understanding, e.g. routine measurements on aircraft to provide a long-time series of relevant conditions, prompt measurements during radiation events (e.g. from balloons and research aircraft) to characterise extreme conditions. Each event may be modest, but the integral of the series may be extreme. Validation of the measurement and modelling approach is needed before we suffer an extreme event. Even a repeat of the event of 23 February 1956 event could exceed recommended dose limits applied in Europe as well as challenging avionics. Also we should explore whether the existing (and vital) measurements from ground-based neutron monitors can be supplemented by exploiting data from cosmic ray soil moisture monitors, as well as systems for monitoring radiation incidents.

3 Specific comments

1. Lower energy electron environments leading to surface charging of satellites should be included. Older spacecraft and new spacecraft with higher power solar arrays are a concern. An electron spectrum in the range 10 -100keV is important, especially in periods of eclipse, and low proton flux, and low density and hot plasma so that the Debye length is large. Substorms are also important here [Fennell et al., 2002].
2. There is more published analysis on ionising radiation for extreme events relating to Medium Earth orbit [Meredith et al., 2016a], and low earth orbit [Meredith et al., 2016b] that is directly relevant and should be used. For MEO it is a direct measure of the charging current without the

problem of proton contamination. Including these studies would provide more confidence in the assessment.

3. For internal charging the document rightly discusses the high energy electron flux due to the radiation belts. However, it should also include a full discussion of the timescales. There are at least two scales to discuss. First, dielectric materials vary by spacecraft and they can take a long time to charge up [Bodeau, 2010]. Thus effects may take place not immediately, but after a CME driving up high energy electron fluxes. Second, a fast CME driven shock can form a new radiation belt in two minutes – as in 1991 which formed a belt near L=2. At these low L values a new belt can then last years and hence cause radiation damage long after the event. Even at GEO the belts can reform and stay elevated to days or weeks. Thus it is during the period after the CME has struck that many satellite anomalies may take place – it may be a long time before the all clear. This emphasises our broader point that you must have enough feedback and iteration between the environment and the effects, you cannot just do the environment alone. You must integrate both.
4. There are other types of events that should be discussed – stream interaction regions associated with fast solar wind streams that can drive up the radiation belts, so they stay elevated for days or weeks. Thus fast solar wind stream events should also be considered as a severe event. This is one example of an area with potential for future collaboration as the EU SPACESTORM project (led by British Antarctic Survey) is completing work on this topic.).
5. For the high energy electron environments that drive internal charging, there is significant variation around the geosynchronous ring. This leads to different extreme conditions for different satellite locations, e.g. some satellites may experience worse conditions than those experienced by GOES.
6. Similarly there are different electron and ion environments for LEO satellites and also for the growing exploitation of MEO (GPS, Galileo) and the broader slot region (e.g. O3B). The growing literature on these regions should be examined and included in the benchmark.
7. We also recommend to consider how geomagnetic cutoff affects extreme environments in the magnetosphere, not least how these change during a large geomagnetic storm when geomagnetic shielding is reduced.
8. We recommend to consider the aging of the spacecraft due to radiation dose and hence what this implies in terms of accumulation of extreme fluence values. This may arise from a series of SEP events closely spaced in time as has been observed in earlier solar cycles. Each event may be modest, but the integral of the series may be extreme.
9. Line 271. Note that the inner belt contains protons with all energies up to a maximum of around 500 MeV .
10. Line 297. Recommend that you explain rigidity.
11. Figure 3. This does give a spectrum for the Feb56 event that looks reasonably consistent with UK work. However the spectra given for September and October 89 events cannot possibly be correct. These were major GLEs (e.g. see the definitive database at http://gle.oulu.fi) and measured on Concorde. The spectra shown in Figure would not give a significant GLE as the slope of the energy spectrum at the highest energy shown is too steep.
12. Figure 5. These spectra are too soft and only go up to about 500 MeV. We believe that the input data you use terminated at 300 MeV. These spectra could not give GLEs. The upper limit at higher energies (say > 300 MeV) appears to be below the actual spectra observed in Feb 56 as shown in your Figure 3. It is therefore not a credible upper limit at these important energies.

13. Line 391. Was the calculation to derive Figure 6 done for an unperturbed magnetosphere in the absence of a geomagnetic storm? Please make clear if this was the case? Can you use MAGNETOCOSMICS to also assess conditions in a large geomagnetic storm?
14. Figure 6. Spectra terminate around 500 MeV. But heavy ions at higher energies will produce copious radiation at aircraft altitudes – roughly speaking every nucleon in a heavy ion will produce a neutron at aircraft altitudes.
15. Page 15. The Tables appear to be reversed? Are the large numbers in table 2 those for the LIS and the lower numbers in table 3 those for the 1-in-100 year case?
16. Table 4. For worst cases you need to extrapolate to the worst case longitude in geosynchronous orbit (around 185 degrees East). Are the cited fluxes those for GOES-West location?
17. Figure 8. Is this the annual fluence and what is the longitude?

4 References

- Bodeau, M. (2010) High Energy Electron Climatology that Supports Deep Charging Risk Assessment in GEO, 48th AIAA Aerospace Sciences Meeting, doi: 10.2514/6.2010-1608
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- Hapgood, M, et al., (2016). Summary of space weather worst-case environments. Revised edition. RAL technical report, RAL-TR-2016-006. http://purl.org/net/epubs/work/25015281.
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- Meredith, N. P., R. B. Horne, J. D. Isles, and J. C. Green (2016b), Extreme energetic electron fluxes in low Earth orbit: Analysis of POES $E > 30$, $E > 100$, and $E > 300$ keV electrons, *Space Weather*, *14*, doi:10.1002/2015SW001348.