Spatial Analysis of Galactic Cosmic Ray Particles in Low Earth Orbit/Near Equator Orbit Using SPENVIS

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Abstract. The space environment has grown intensively harmful to spacecraft and astronauts. Galactic cosmic rays (GCRs) are one of the radiation sources that composed of high energetic particles originated from space and capable of damaging electronic systems through single event upset (SEU) process. In this paper, we analyzed GCR fluxes at different altitudes by using Space Environment Information System (SPENVIS) software and the results are compared to determine their intensities with respect to distance in the Earth’s orbit. The altitudes are set at low earth orbit (400 km and 685 km), medium earth orbit (19,100 km and 20,200 km) and high earth orbit (35,793 km and 1,000,000 km). Then, within Low Earth Orbit (LEO) near the equator (NEqO), we used altitude of 685 km to compare GCRs with the intensities of solar particles and trapped particles in the radiation belt to determine the significance of GCRs in the orbit itself.

Keywords: Galactic cosmic rays, SPENVIS, Low earth orbit, Near equatorial orbit

1. Introduction
Space radiation environment is made up of three principle sources, mainly galactic cosmic rays (GCRs), trapped particles and solar particle events (SPE) [1]. GCRs are composed of 87% are protons, 12% are helium ions and 1% is heavy ions [2]. Trapped particles consisted of protons and electrons trapped in the Earth’s geomagnetic field called the Van Allen’s radiation belts where they moved in complex motion. SPE are energetic particles emitted by the sun during solar flares and coronal mass ejections (CMEs) where it included electrons, protons and heavier charged particles. All three sources are affected by the Earth’s magnetic field [1]. However, magnetic polarity only affects GCR fluxes and not trapped particles or solar particle event fluxes [3].

Many spacecraft and artificial satellites are located at low earth orbit (LEO) because higher orbits put them at risk of higher radiation damage and exposure. However, despite being at low altitudes, they are still exposed to relatively high radiation because of variations in the solar cycle phase [3]. Due to the wide range of heavier ions, they have high LET and can be highly penetrating, hence capable of posing damaging consequences.

1.1 Galactic Cosmic Rays
GCR is dependent on solar activity whereby its intensity is at the highest during solar minimum and lowest during solar maximum conditions [4]. Charged particles had the tendency to follow the Earth’s geomagnetic field lines. They tend to point towards the surface at higher inclinations, allowing deeper penetration of incident particles so GCR quite often dominate at the poles. The field lines are parallel to the surface at lower inclinations so when GCR hit Earth, most are often deflected away.
1.2 SPENVIS
It is a powerful software application developed and maintained at Belgian Institute for Space Aeronomy (BIRA-IASB) since 1996 and is an on-going European Space Agency (ESA) project that incorporated many models and tools to describe the space environment and its effects on materials [5,6]. It is accessed online and is available through its homepage http://www.spenvis.oma.be.

2. Methodology
This paper contained two aims. The first was to look into GCR fluxes at different altitudes to determine the significance level of GCR at low earth orbit (LEO) as compared to middle earth orbit (MEO) and high earth orbit (HEO). The second aim was to compare the GCR fluxes with that of trapped particles and SPE to determine significance level between the three radiation sources. We used Razaksat satellite orbit data because the focus of this research was on LEO/NEqO in which Razaksat was the best representative with nominal altitude of 685 km at 9° inclination. The software tool used was SPENVIS as it allowed users to generate orbital parameters to determine space weather conditions hence, it was a suitable tool to fulfill both aims.

2.1 Altitude Dependency
Orbital data are obtained following the availability of well-known satellites. The altitudes used to represent different orbits are shown in Table 1.

Mrigakshi et al [7] described that there was a significant peak of GCR in November 2009 in which that particular month was the solar minimum occurring between solar cycles 23 and 24. The comparison of GCR intensities between solar maximum and solar minimum following Razaksat orbital data is shown in Figure 1. Solar maximum was taken during Halloween Storm 2003 which occurred from 19 October until 7 November 2003 [8]. It appeared that there was no significant difference. Therefore, we used 30 days data from November 2009 throughout this study under a quiet magnetosphere.

Table 1. Altitudes taken from each orbits following the orbital data of selected satellites

| Low Earth Orbit (LEO) | Middle Earth Orbit (MEO) | High Earth Orbit (HEO) |
|-----------------------|--------------------------|------------------------|
| 400 km                | 19,100 km                | 35,793 km              |
| 685 km                | 20,200 km                | 1,000,000 km           |

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Figure 1. GCR fluxes during solar maximum and solar minimum generated from SPENVIS.
2.2 Space Radiation Environment in LEO/NEqO Orbit
Because proton made up about 87% in GCR composition, we used hydrogen particle to represent the GCR flux in this study. Then we compared it with the fluxes from trapped particles and the solar particle event at a fixed altitude of 685 km, following Malaysian satellite Razaksat orbital data in representing LEO/NEqO orbit.

3. Results and Discussion
A comparison of hydrogen particle fluxes at different altitudes is presented in Figure 2. All fluxes showed a declining trend with increasing energies but increase with respect to altitudes. However, hydrogen flux at 400 km is higher than that at 685 km due to different inclinations input in SPENVIS. At 400 km the inclination was set at 51.65° following the ISS satellite orbital data while the inclination for the altitude 685 km was set as 9° which followed the Malaysian satellite Razaksat orbital data.

![Figure 2. Hydrogen fluxes at different altitudes on November 2009 (average 30 days data)](image)

Because radiation exposure of spacecraft in LEO is dependent on orbit inclination and altitudes [1], the following Figures 3, 4 and 5 showed how different inclinations would affect GCR intensities for three types of orbits. There was a significant difference of hydrogen fluxes at different orbital inclinations in LEO. However, they are the same for MEO and HEO cases regardless of orbital inclinations.
Figure 3. Hydrogen fluxes at different inclinations in low earth orbit (LEO)

Figure 4. Hydrogen fluxes at different inclinations in middle earth orbit (MEO)

Figure 5. Hydrogen fluxes at different inclinations in high earth orbit (HEO)
Within LEO at the altitude of 685 km contained GCR with energies 10 GeV and above, trapped proton of less than 400 MeV and trapped electron of less than 10 MeV (Figures 6 and 7). This showed that in LEO/NEqO orbit, GCR and trapped particles occupied different range of energies with each being dominant at specific energy level. In other words, LEO/NEqO orbit contained high energy GCR and relatively lower energy trapped particles. The maximum fluxes for each particle type are in Table 2. The solar particle events, however, had no values obtained through SPENVIS using the Razaksat orbital data (figure not shown).

**Table 2.** Peak values for galactic cosmic ray and trapped particles at 685 km altitude following Razaksat satellite orbital data

| Particles      | Peak Values               |
|----------------|---------------------------|
| GCR            | $\sim 0.007 \text{ m}^2\text{sr}^{-1}\text{s}^{-1}\text{(MeV/n)}^{-1}$ |
| Trapped Proton | $\sim 2 \text{ cm}^{-2}\text{s}^{-1}\text{(MeV)}^{-1}$     |
| Trapped Electron| $\sim 500 \text{ cm}^{-2}\text{s}^{-1}\text{(MeV)}^{-1}$   |

**Figure 6.** GCR and trapped proton fluxes at 685 km altitude

**Figure 7.** GCR and trapped electron fluxes at 685 km altitude
4. Conclusion and Future Work
This study aimed to describe GCR in the form of hydrogen flux in LEO/NEqO orbit by using SPENVIS. Consequently, altitudes played a role in GCR exposure to spacecraft and astronauts whereby higher altitudes gave higher GCR intensities. On the other hand, orbital inclinations have effect only towards LEO orbits but made no difference in MEO and HEO orbits in regards with GCR intensities.

Within LEO/NEqO orbit contained GCR and trapped particles but no solar particle events were detected through SPENVIS. Between the two space radiation sources, GCR dominated the higher energy range of about 10 GeV and above while trapped particles dominated the lower energy range of 400 MeV for trapped protons and 1 MeV for trapped electrons.

Space radiation consisted of three principle sources that included GCR, trapped particles and SPE, however, SPE were unable to be detected from SPENVIS. Hence, in order to better assess LEO/NEqO orbits, it would be interesting if all the three sources can be determined. Other methods such as Geant4 or International Space Station (ISS) data source can be implemented to obtain the missing SPE data. The actual level of risk posed by GCR can be further investigated through comparison with polar orbits. Moreover, materials such as gallium-arsenide or silicon that made up the satellites are protected by aluminium shielding and by considering various thicknesses can determine the level of protection it provided against the space radiation environment.

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References
[1] Benton E R and Benton E V 2001 Space radiation dosimetry in low-Earth orbit and beyond Nucl. Instr. and Meth. In Phys. Res. B 184 255-294
[2] Simpson J A 1983 Elemental and isotopic composition of the galactic cosmic rays Annu. Rev. Nucl. Part. Sci. 33 323 382
[3] Bourdarie S and Xapsos M 2008 The space radiation environment IEEE Trans. in Nucl. Sc. (TNS)
[4] Badhwar G D and O’Neill P M 1996 Galactic cosmic radiation model and its application Adv. Space Res. 17 (2)7-(2)17
[5] Kruglanski M, Messios N, Donder E D, Gamby E, Calders S, Hetye L, Evans H and Daly E 2009 Last upgrades and development of Space Environment Information System (SPENVIS) IEEE 978-1-4577-0493-2
[6] Lawrence G, Reid S and Kruglanski M 2010 Space Environment Information System: Applicability for mission design and operations American Institute of Aeronautics and Astronautics
[7] Mrigakshi A I, Matthia D, Berger T, Reitz G and Wimmer-Schweingruber W 2013 Estimation of galactic cosmic ray exposure inside and outside the Earth’s magnetosphere during the recent solar minimum between solar cycles 23 and 24 Adv. Space Res. 52 979-987
[8] http://www.nasa.gov/topics/solarsystem/features/halloween_storms.html