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Space radiation environment in low earth orbit during solar-activity minimum period from 2006 through 2011

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ABSTRACT

The Technical Data Acquisition Equipment on board the Advanced Land Observing Satellite had been operated in low earth orbit at 700 km altitude from 2006 through 2011 in order to evaluate space radiation environment, especially the proton environment and the electron environment in the radiation belts, during solar-activity minimum period. The activation of the electron environment in the inner radiation belt along with the 24th solar-activity cycle started in the beginning of 2010, 1 year after the beginning of the 24th solar-activity cycle itself in the end of 2008. The electron environment in the outer radiation belt was almost always modulated by solar wind variations; however, it showed very low activities in the beginning of 2010 which was the same time when the lowest activities were seen in the inner radiation belt. On the other hand, the proton environment in the inner radiation belt showed a slight increase as solar activity went lower, and had a peak also in the beginning of 2010, the same time when there was maximum galactic cosmic ray flux. 1-year delay of the response of space radiation environment around the Earth is suggested to be because the beginning of the 24th solar-activity cycle was very quiet as compared with the several former solar-activity cycles.

1. Introduction

Long-term measurement of space environment is an essential issue to understand its variation along with solar-activity cycle for reliable design and safety operation of space missions. Especially, measurement in space is a unique method to know directly how space environment responds to solar and geomagnetic activities. Consecutive measurement by a single instrument is also an important point to avoid calibration problems. However, long-term measurement in space using a single instrument is a rare work because of limitation of spacecraft lifetime.

In this paper, measurement of space radiation environment in low earth orbit using a single instrument carried out from 2006 through 2011 is reported, which covers a half of solar-activity cycle. This period is well known as peculiar deep solar-activity minimum so that space radiation environment around the earth as consequences of solar and geomagnetic activities is considered to be also peculiar as compared with those seen in the several former solar-activity cycles.

2. Measurements

The ALOS satellite (Advanced Land Observing Satellite: so-called Daichi in Japanese) was developed by the Japan Aerospace Exploration Agency (JAXA) to contribute to the fields of mapping, disaster monitoring, and resource surveying. This satellite was launched on 24 January 2006, and had been operated until 12 May 2011 for about 5 years. The orbital parameters of this satellite were 700 km altitude, 98° inclination, and 46 days recurrent period (see JAXA Home Page). The TEDA (Technical Data Acquisition Equipment) was on board this satellite to evaluate space radiation environment in low earth orbit for the safe operation of this satellite as well as for the development of precise space radiation environment model (see SEES Home Page).

The TEDA consisted of the Light Particle Telescope (LPT) for measurement of energetic electrons, protons, and alpha-particles, and the Heavy Ion Telescope (HIT) for observation of energetic ions. The LPT was composed of 8 solid-state detectors. The aperture angle and the geometric factor were 21.5° and 0.071 cm^2 sr, respectively. The LPT had a capability to measure electrons in the energy range from 0.1 MeV to 10 MeV, protons from 1 MeV to 250 MeV, and alpha-particles from 6 MeV to 250 MeV with 1-s temporal resolution. The LPT could also distinguish nuclei of hydrogen and helium isotopes. The HIT was composed of 2 position-sensitive detectors and 16 solid-state detectors. The aperture angle and the geometric factor were 45° and 25 cm^2 sr, respectively. The HIT had a capability to measure

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ions (helium–iron) from 5 MeV/nucleon to 155 MeV/nucleon. Both the LPT and the HIT adopted the ΔE–E method to distinguish nucleus and energy of incident particles (e.g., Goulding and Harvey, 1975). The center of the field of view of both the LPT and the HIT was 45° inclined from the zenith in the opposite direction of the satellite movement.

In this study, energy ranges at around 10 MeV for protons and 1 MeV for electrons are chosen to evaluate space radiation environment, because particles in these energy ranges have the highest population among particles that can penetrate spacecraft walls. Analyzed period is also selected such as from September 2006 through February 2011 where measurement had been carried out stably. Additionally, proton flux and electron flux at Geo-Stationary orbit are used, which were obtained by the SDOM (Standard Dose Monitor) on board the DRTS satellite (Data Relay Test Satellite: so-called Kodama in Japanese) (see JAXA Home Page, SEES Home Page).

3. Results

Figs. 1 and 2, respectively, illustrate the geographic distribution of proton flux and electron flux averaged over the analyzed period except strongly disturbed period by solar and geomagnetic events. The distributions are, in principle, determined by the geomagnetic cut-off rigidity distribution except in the SAA (South Atlantic Anomaly) region that corresponds to the inner radiation belt. Both proton flux and electron flux become higher as the rigidity goes lower. The distribution of electron flux also shows the horn region that corresponds to the foot point of the outer radiation belt. In low earth orbit, the SAA region is the dominant contributor to both the proton environment and the electron environment. However, in case of solar and geomagnetic events, the proton environment in the polar region and the electron environment in the horn region are seriously disturbed.

These results are obtained from the measurement in low earth orbit carried out near the bounce loss cone; however, these can exhibit the whole aspects of trapped particles in the radiation belts, because time scale of these particles to reach equilibrium when supplied is much shorter than solar-activity cycle so that these particles are considered to be coherent for wide L-shell range in long-averaged measurement in this study (e.g., Imhof et al., 1991; Kanekal and Baker, 2001).

Figs. 3 and 4, respectively, demonstrate the L–t diagram of proton flux and electron flux during the analyzed period. Proton flux in the inner radiation belt at around $L=1.5$–2 was almost

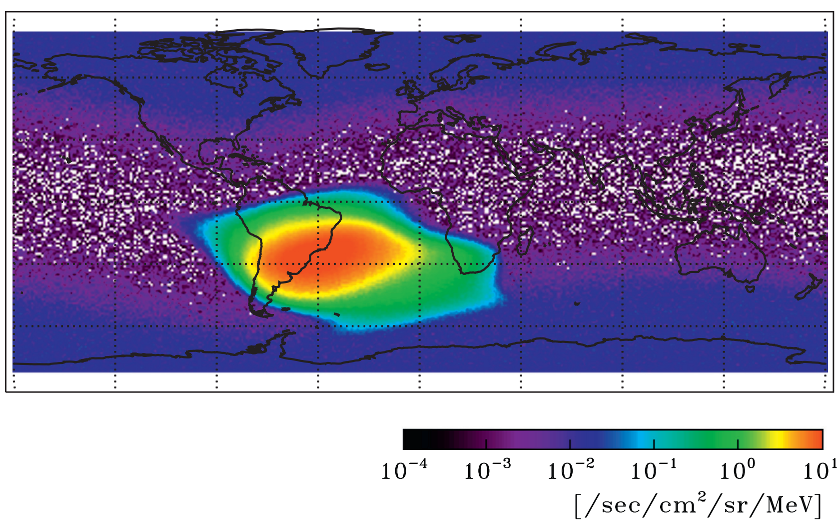

Fig. 1. Geographic distribution of proton flux in the energy range from 7 MeV to 18 MeV averaged over September 2006–February 2011.

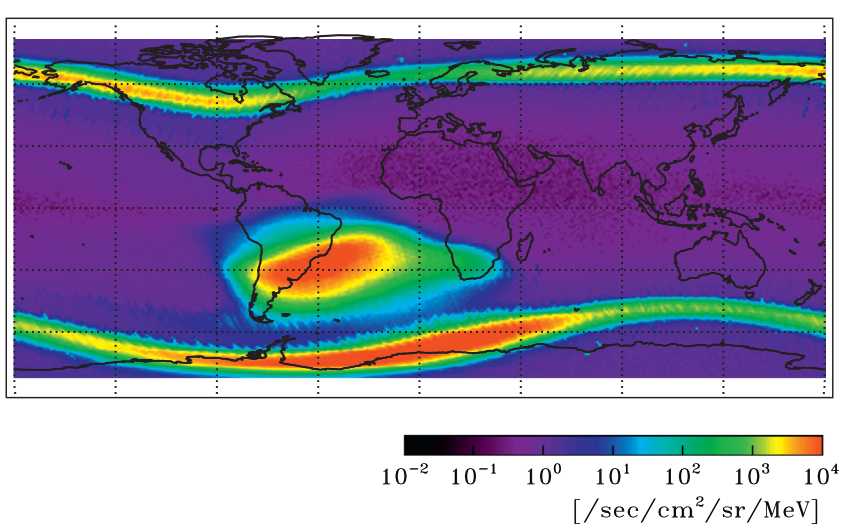

Fig. 2. Geographic distribution of electron flux in the energy range from 0.6 MeV to 1.2 MeV averaged over September 2006–February 2011.