Space radiation enhancement linked to geomagnetic disturbances

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Abstract Space radiation dosimetry measurements have been made on board the Space Shuttle. A newly developed active detector called "Real-time Radiation Monitoring Device (RRMD)" was used (Doke et al., 1995; Hayashi et al., 1995). The RRMD results indicate that low Linear Energy Transfer (LET) particles steadily penetrate around the South Atlantic Anomaly (SAA) without clear enhancement of dose equivalent and some daily periodic enhancements of dose equivalent due to high LET particles are seen at the lower geomagnetic cutoff regions (Doke et al., 1996). We also have been analyzing the space weather during the experiment, and found that the anomalous high-energy particle enhancement was linked to geomagnetic disturbance due to the high speed solar wind from a coronal hole. Additional analysis and other experiments are necessary for clarification of these phenomena. If a penetration of high-energy particles into the low altitude occurs by common geomagnetic disturbances, the prediction of geomagnetic activity becomes more important in the next Space Station's era.

1. Introduction

In the 21st century, it is expected that manned space activities and space utilization will make further progress. The low earth orbit will soon become a permanent living area, and the geosynchronous orbit will be overcrowded by many kinds of utility satellites. On the other hand, space is a harsh environment bathed with radiation and penetrated by streams of energetic particles. If adequate space "radiation" weather operation is not provided, future astronauts could be exposed to radiation doses and equipment on the spacecraft could suffer some damaging effects. Especially when the structure of the radiation belt is deformed by geomagnetic disturbance due to the solar wind disturbance as shown in Fig. 1, space becomes more hazardous to astronauts and space equipment even in low altitude orbit. In order to utilize an outer space environment in security, a Space Weather Forecast (SWF) system as shown in Figs. 2 and 3 is necessary. The SWF research and development project is designed to improve the accuracy of the space environment prediction by increasing our understanding of how activities on the sun affect space near the earth, and by developing the observation technology necessary for this purpose. The research of the radiation environment in the magnetosphere has been energetically pushed forward (e.g., Baker, 1996; Feynman, 1996; Shea et al., 1996; Gussenhoven et al., 1992). And the prediction algorithm of high-energy particles at the geosynchronous orbit has been developed (Stringer et al., 1995; Baker et al., 1990; Nagai, 1988). In regard to the low altitude, some satellites' observations have been producing noteworthy results (Nagai et al., 1995; Ryowa et al., 1995; Baker et al., 1994; Cummings et al., 1993; Kohno et al., 1990; Kikuchi et al., 1989). One of the objectives of our experiments is to determine how the outer space environment between the sun and the earth influences the radiation environment at the low earth orbit. This kind of experiment should make it possible to predict the radiation environment near the earth by using the data of the solar and interplanetary environment.

Fig. 1 A flow diagram showing the space weather linkages.

Fig. 2 One of the strategic plan for the space weather forecast
2. Observation

Space radiation dosimetry measurements have been made on board the STS-65 in 1994 (Table 1). The detectable particles by RRMD are also listed. The main result of the RRMD experiment is summarized by Doke et al., 1996. Other biological experiments concerning to the biological effects of the radiation were also performed.

A count rate of the RRMD usually shows a periodic particle penetration around the SAA as shown in Fig. 4. This stationary penetration is also shown in a summary map in Fig. 5. However, a small unexpected enhancement was observed around 14 h UT on July 14 as shown in Figs. 4 and 6. The cause of this enhancement is clearly different from the SAA. At first, the cause of this event was suspected to be a Solar Particle Event (SPE) by RRMD ground operators during the experiment. However, real time analysis of the space weather at Hiraiso made it clear that there was little possibility of SPE. For the purpose of the quick responses required in this situation, our space weather information system (Ishibashi et al., 1996) showed its power.

3. Space weather analysis

In order to perform the data analysis, other space weather data are examined. A summary of the space weather between July 10 and July 22 is reported as follows.

<table>
<thead>
<tr>
<th>Period</th>
<th>251.3 hr from July 8 to July 23, 1994.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit</td>
<td>Inclination=28.5°, Altitude<del>300 km, Orbital period</del>90 min.</td>
</tr>
<tr>
<td>Detectable particles and energy range (MeV):</td>
<td>He; 10-55, C;18-110, Ne; 24-130, Mg;26-160, Si;28-180, Ca;34-210, Fe/Ni;38-210</td>
</tr>
</tbody>
</table>

Related experiments:
- Measurements of LET distribution and dose equivalent on board the space shuttle STS-65 (IML-2), Principal Investigator: T. Doke, Co-investigator: J. Kikuchi, T. Hayashi, N. Hasebe, G. D. Badhwar, S. Nagaoka, M. Kato.,
Fig. 4. The count rate of RRMD from July 13 to 16. Periodic enhancement of PSD1 and PSD2 are caused by the South Atlantic Anomaly, and there is another small enhancement around 14 hUT (3 - 7 h LT) on July 14.

Fig. 5. Overlapping of the 12 hours contour maps which shows the area where the number (LET>5.02 eV/um) of the PSD1 count excess of 7 from July 15, 0 hUT to July 21, 12 hUT.

Fig. 6. One 12 hours contour maps of during 12:00 - 24:00 UT on July 14. Anomalous counts corresponding to the 14 hUT event in Fig. 4 are shown by contours from 5°N to 20°N.

3.1. Solar activity and interplanetary weather
A calm solar condition continued during the period. Flares of above C class activity are listed in Table 2.

Interplanetary weather was calm until July 13, but the high speed solar wind from a coronal hole had been observed since July 14 as shown in Fig. 7.

3.2. Radiation Environment at the geosynchronous orbit
The solar activity was quite calm as mentioned above, and a SPE had not occurred. The energetic electron flux around the geosynchronous orbit became higher after July 14 as shown in Fig. 8. The cause of this event was a high-speed solar wind from a coronal hole. Though the operators of geosynchronous satellites had to take precautions to prevent the radiation effects, it is thought that there was no influence to a low earth orbit satellite at all.

Table 2. Flares of above C class activity

<table>
<thead>
<tr>
<th>Date &amp; Time (UT)</th>
<th>X-ray/Optical</th>
<th>Region</th>
<th>Radio Sweep</th>
</tr>
</thead>
<tbody>
<tr>
<td>707 0956</td>
<td>M1.3 /IN</td>
<td>7746</td>
<td>2, 3, 4</td>
</tr>
<tr>
<td>708 0537</td>
<td>C1.0 /SF</td>
<td>7749</td>
<td></td>
</tr>
<tr>
<td>712 0915</td>
<td>C6.0 /IN</td>
<td>7746</td>
<td>2</td>
</tr>
<tr>
<td>714 0844</td>
<td>C1.9 /SF</td>
<td>7746</td>
<td>3</td>
</tr>
<tr>
<td>714 1955</td>
<td>C2.3 /SF</td>
<td>?</td>
<td>3, 5</td>
</tr>
<tr>
<td>715 0714</td>
<td>C1.1 /SF</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>715 1713</td>
<td>C1.1 /SF</td>
<td>7754</td>
<td></td>
</tr>
<tr>
<td>716 0251</td>
<td>C1.4 /SF</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>718 1330</td>
<td>C3.2 /SF</td>
<td>7758</td>
<td>2, 3, 4, 5</td>
</tr>
</tbody>
</table>
Fig. 7. Solar wind by IMP-8.

Fig. 8. An energetic particle environment around the geosynchronous orbit is observed by the SpaceEnvironment Monitor (SEM) loaded on the Japanese meteorological satellite (GMS). There is a moderate enhancement on EL channel and no Solar Particle Event on P2 channel.

Fig. 9. Summary plots of geomagnetic activity. Data by Meteorological Agency Kakioka Geomagnetic Observatory, and indication is performed by Hiraiso Solar Terrestrial Research Center.
3.3. Geomagnetic activity

A summary of the geomagnetic activity is shown in Figs. 9 and 10. Though the first half of the period was quite calm, a disturbance of about 50 nT in Dst at the maximum began from 10 h UT on July 14. This is caused by the high speed solar wind from a coronal hole which was crossing the meridian of the sun on July 12.

4. Discussion

In the RRMD experiment, high-energy heavy particles in the Space Shuttle were measured. Because the experiment had been conducted during the solar minimum phase of about 11-years solar cycle as shown in Fig. 11, and there were no significant solar events, almost all detected particles are caused by the SAA or a part of the Galactic Cosmic Ray (GCR) flux. Though there is an exceptional enhancement of high-energy particles on July 14 as shown in Figs. 4 and 6, the cause of this event is not thought to be the SPE as referred to the above analysis. The flare activity which we might consider as a cause of above event before 14 h UT on July 14 are C6.0/1N and C1.9/SF both at #7746, but these events are quite common and is accompanied by no energetic event such as strong radio sweep as shown in Table 2. The Solar Energetic Particles (SEPs) were not observed in a geosynchronous orbit either as shown in Fig. 8. However, since the radiation detector used in this investigation is much more sensitive than a GMS/SEM, no SEP observation by GMS or GOES is not a sufficient condition. As seen in the GMS/SEM data and in the ground based observations, the geomagnetic disturbance due to the high speed solar wind from a coronal hole began July 14. For the present, the cause of the above event is thought to be a slight particle leak from the radiation belt or of the galactic cosmic ray due to the geomagnetic disturbance. The leak of the GCR is rather improbable, because no enhancement was observed in the high energy channel as shown in Fig. 4. Additional analysis and other low altitude experiments are necessary for clarification of these phenomena. If a penetration of heavy particles into the low earth orbit occurs by a common geomagnetic disturbance, the prediction of a geomagnetic activity becomes more important for the next Space Station's era.

5. Acknowledgments

We thank the many individuals who have contributed so extensively to the success of IML-2 mission. We also thank the individuals who have contributed to the following data handling systems which have been useful in this experiment and analyses: Space weather information system at Hiraiso Center (Ishibashi et al., 1996). Space weather information system at NOAA Space Weather Operation (Hirman et al., 1996). Particle data by GMS/Japanese Meteorological Agency, GOES/NOAA, and ETS/NASDA. Geomagnetic data from Kakioka Observatory. Dst index from WDC-C2/Kyoto University. Preliminary Report and Forecast of Solar Geophysical Data by NOAA/SWO. Solar-Geophysical Data comprehensive reports by NOAA/SWO.
6. References of data

The following systems and data were utilized in this experiment and analyses.

Observation data and the space weather information system at the Hiraiso Solar Torus Research Center.
Space weather information system at the Space Environment Center, NOAA, US Dept. of Commerce.
Particle data. (GEMS/Meteorological Agency, GOES/NOAA, US Dept. of Commerce, ETS/NASA.)
Geomagnetic data. (Kakioka Geomagnetic Observatory / Meteorological Agency)
Dst index data. (WDC-C2 / Kyoto University)
Solar-Geophysical Data comprehensive reports, NOAA/SWO, US Dept. of Commerce.

7. References


Kikuchi, T., and D.S. Evans, Energetic electrons observed by NOAA6 over Japan (L=1.3) at the time of geomagnetic storm on February 8-9, 1986, Proc. Research Institute of Atmospherics, Nagoya Univ., 36, 137, 1989.


