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Solar wind dependence of the electron flux variation at geostationary orbit observed by ETS-V

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Abstract: In this study we have examined the relationship between the energetic electron flux at geostationary orbit and the solar wind speed. We have compared the electron flux (>0.4 MeV) observed by the Engineering Test Satellite V (ETS-V) with solar wind speed measurements in the OMNI data set obtained from the National Space Science Data Center (NSSDC). The tendency has been observed for the logarithm of the electron flux to be proportional to the solar wind speed at solar minimum, but scattered at solar maximum. We have found that during the main and recovery phases of magnetic storms occurring at solar minimum, the logarithm of the electron flux is roughly proportional to the solar wind speed. At solar maximum, however, there is no apparent correlation between both these parameters. Moreover, in quiet periods there is also no observable correlation at both solar minimum and maximum. The dependence of the electron flux at geostationary orbit on the solar wind speed is related to recurrent storms caused by high-speed solar wind streams.

1. Introduction

The number of energetic particles in the Earth's outer radiation belt varies in response to the solar-terrestrial environment; that is, to the Earth's magnetic field, the interplanetary condition, solar activity, and so on. Studying the dynamical change of energetic particles in the outer radiation belt is important for solving various scientific problems as well as for practical applications.

McIlwain (1966) demonstrated that high-energy electrons disappear at geostationary orbit whenever a geomagnetic storm occurs, and that the electron flux was related to geomagnetic disturbances. The decrease and subsequent increase in the electron flux at geostationary orbit during a geomagnetic storm, often to a level higher than the pre-storm level, has been discussed in studies on the variation of energetic particles in the outer radiation belt with variations in the Earth's magnetic field. Several explanations have been proposed for the behavior of high-energy electron fluxes during geomagnetic storms, *e.g.,* adiabatic and non-adiabatic processes caused by a *Dst* field change (McIlwain, 1996; Kim and Chan, 1997; Nakamura *et al.,* 1998). Interplanetary conditions are also thought to be an important factor in the electron flux variation in the outer radiation belt. High-speed solar wind streams (Baker *et al.,* 1986) and the southward component of the interplanetary magnetic field (Obara *et al.,* 1998) are thought to lead

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to the production of high-energy electrons. Recently, several papers have been published suggesting that the energy of magnetospheric electrons is provided by ULF waves (*e.g.,* Rostoker *et al.,* 1998; Elkington *et al.,* 1999; Liu *et al.,* 1999; Mathie and Mann, 2000). Rostoker *et al.* (1986) have found that Pc5 wave power is correlated with the high-energy electron flux, and physical explanations are provided by Elkington *et al.* (1999) and Liu *et al.* (1999). Mathie and Mann (2000) have recently also demonstrated that the Pc5 ULF wave power is closely related to energetic electrons at geostationary orbit as well as fast solar wind streams in the solar declining phase. However, these physical processes are not fully understood.

In space weather studies, much attention is paid to the behavior of high-energy electrons, since their enhancement is considered to cause fatal damage to spacecraft by causing internal electric discharges (Gussenhoven *et al.,* 1991; Baker *et al.,* 1994). Recently, the importance of the particle dynamics in the radiation belt has been recognized in spacecraft anomaly research. Various attempts have been made to predict the electron flux measured at geostationary orbit (*e.g.,* Nagai, 1988; Tsutai *et al.,* 1999).

In the present paper, we have examined how the electron flux measured at geostationary orbit depends on the solar wind speed during both magnetic disturbances and quiet periods. Baker *et al.* (1986) have found that enhancements of the highly relativistic electron flux occur relatively infrequently around solar maximum, but occur periodically in correlation with high-speed solar wind streams in the subsequent declining phase of solar activity. Li *et al.* (1997) have described recurrent enhancements of the high-energy electron flux associated with high-speed solar wind streams. One of our objectives is to determine which conditions cause enhancements in the electron flux initiated by high-speed solar wind flows. This is also the first scientific report on the ETS-V/DOM data developed by the National Space Development Agency of Japan (NASDA).

2. Instrument

Electrons, protons, and heavy ions in the outer radiation belt have been measured by a dosimeter (DOM) mounted on ETS-V. ETS-V was launched on 27 August 1987 in order to establish basic technologies for geostationary satellites. Its orbital altitude is about 36000 km, and is located at 150°E in geographic longitude and 8.4°S in geomagnetic latitude. One of the missions of ETS-V involved the testing of the technical data acquisition equipment (TEDA), which is an integrated monitoring system of the space environment and its effects on spacecraft. TEDA consists of eight instruments, including the DOM for recording long-term variations in the flux and properties of energetic particles. The DOM is designed to count electrons (>0.4 MeV), protons (6 to 60 MeV), and heavy ions (>60 MeV) restricted by a geometric factor, 1.5×10^{-3} (cm^2/str). The electron and heavy ion counts are the number of incoming particles in energy ranges assigned by DOM (detailed in Nishimoto *et al.,* 1997). DOM data were obtained from November 1987 to September 1997.

3. Data analysis procedure

We used the high-energy electron flux (>0.4 MeV) at geostationary orbit observed by ETS-V/DOM, the solar wind speed, and the *Dst* index from 1987 to 1997. Solar wind speed was obtained from the National Space Science Data Center and the *Dst* index obtained from the World Data Center C2 at Kyoto University. Figure 1 shows a sample data plot for 1996. The horizontal axis is the month of the year. From the top panel, the solar wind speed, the electron flux by ETS-V/DOM, the north-south component of the interplanetary magnetic field, and the *Dst* index are shown. Recurrent enhancements of the energetic electrons corresponding to the solar wind speed can be seen. Figure 2 shows the sunspot number as a function of year in histogram form, and the Ap^* index as a solid line. The right-hand vertical axis shows the Ap^* index, and

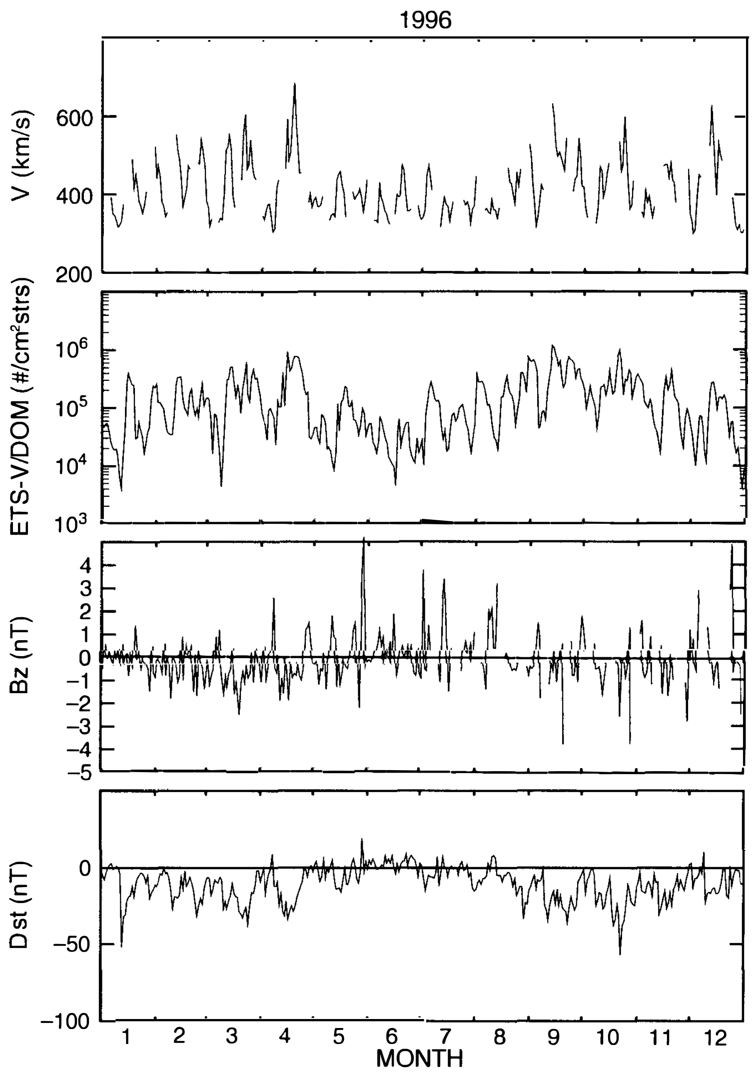

Fig. 1. Sample data plots for 1996. The horizontal axis is the month of the year. The solar wind speed, the electron flux observed by ETS-V/DOM, the north-south component of the interplanetary magnetic field, and the Dst index are shown from the top panel in order.

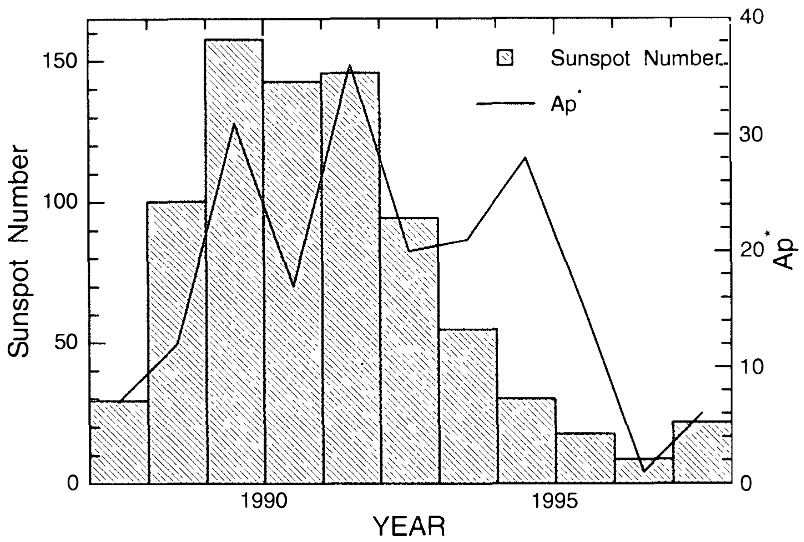

Fig. 2. The sunspot number and the Ap index. The horizontal axis is the year. The right-hand vertical axis shows the Ap* index and the left-hand vertical axis shows the sunspot number. The sunspot number is shown as a function of the year by the histogram and the Ap* index is shown in the solid line.*

the left axis shows the sunspot number. The ETS-V/DOM data covered one solar cycle as seen in Fig. 2.

In order to examine the correlation between the electron flux and the solar wind speed, we have selected two values of each at local noon, that is, two at 0200 UT, since the ETS-V was located at UT +10 hrs. Selected values have been plotted as electron flux versus solar wind speed. The results are plotted in the following section. Furthermore, we have separated the points on the plot into four classes, *i.e.,* the initial phase, main phase, and recovery phase of a magnetic storm, and the quiet period based on the *Dst* index. Quiet periods are defined as *Dst* greater than −10 nT. Each phase of a magnetic storm is identified by visual inspection.

4. Results

Figure 3 shows a scatter plot of the solar wind speed and the electron flux in 1989, that is, at solar maximum. The horizontal and vertical axes are the solar wind speed and electron flux respectively. These points are highly scattered, and there is no apparent correlation between the solar wind speed and the electron flux. Figure 4 shows a scatter plot of the above two quantities in the same format as that of Fig. 3 for 1996, that is, at solar minimum. Unlike the result at solar maximum, we can see that the electron flux is proportional to the solar wind speed in Fig. 4. It has been found that the correlation between the solar wind speed and the electron flux at solar maximum is different from that at solar minimum.

Figure 5 shows scatter plots of the solar wind speed and the electron flux for quiet periods in the same format as that of Fig. 3. The top and bottom panels of left side are for high solar activity and them of right side are for low solar activity respectively. In Fig. 5 there is little apparent difference between the correlation at solar maximum and

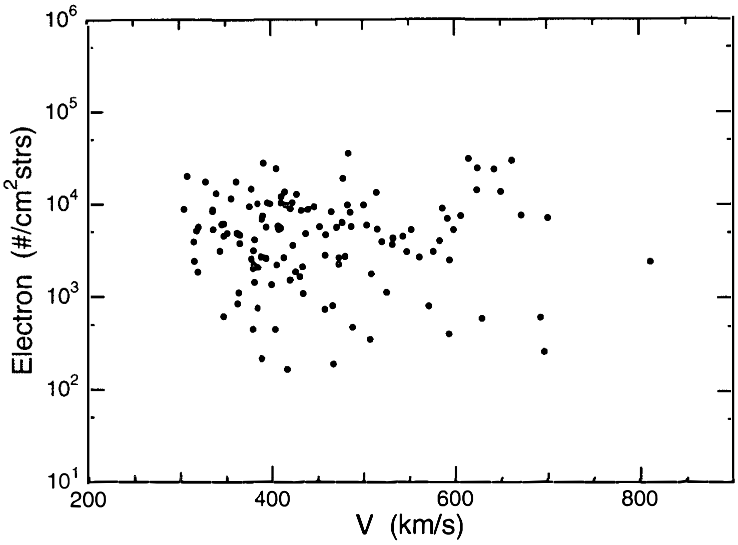

Fig. 3. A scatter plot of the solar wind speed and the electron flux in 1989 (solar maximum). The horizontal axis is the solar wind speed and the vertical axis is logarithm of the electron flux measured by ETS-V/ DOM.

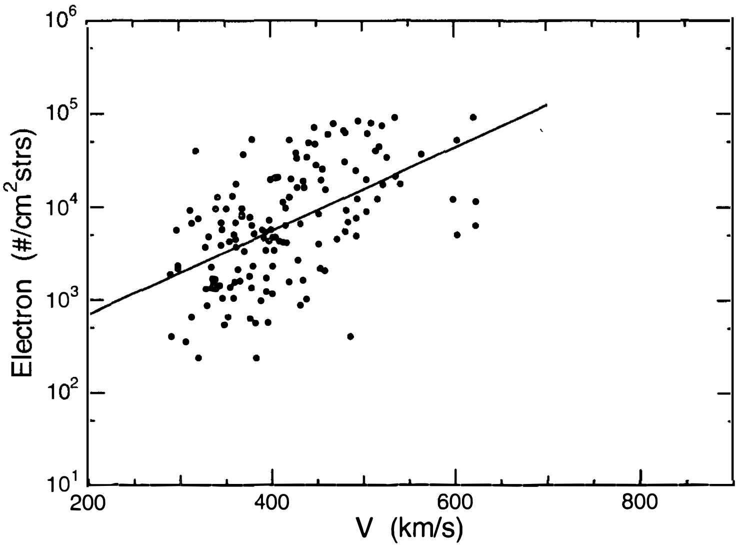

Fig. 4. A scatter plot in the same format as Fig. 3 for 1996 (solar minimum).

at solar minimum. Figure 6 shows scatter plots in the same format as that of Fig. 3. The left two panels are for solar maximum in 1989 and the right two panels are for solar minimum in 1996. The top and bottom panels display plots for the main storm phase and the recovery phase respectively. It has been shown that the electron flux tends to correlate with the solar wind speed at solar minimum. The dependence of the electron flux on the solar wind speed has been seen for the main and recovery phases of a magnetic storm rather than for the quiet periods.

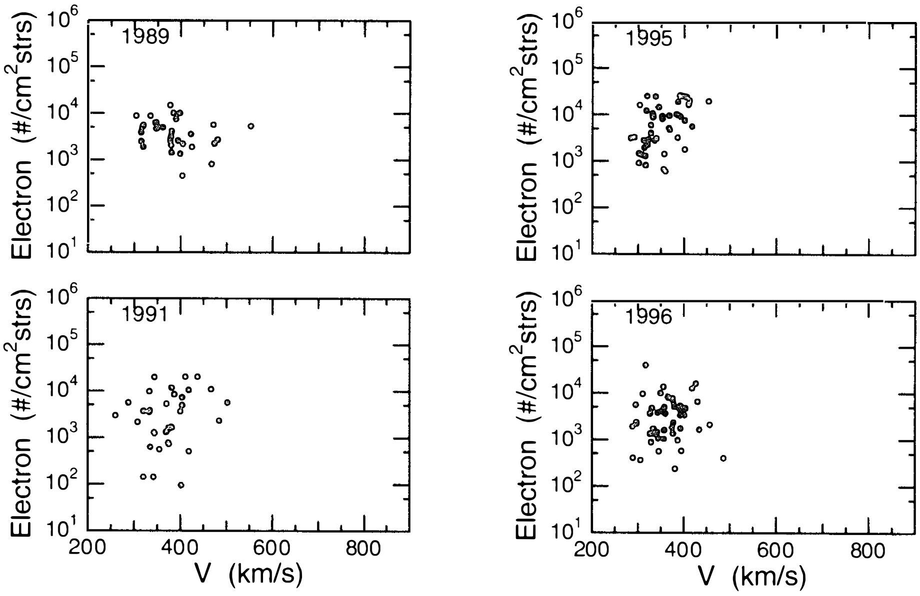

Fig. 5. Scatter plots in the same format as Fig. 3 for the quiet periods. The left two panels are for high solar activity (the top for 1990 and the bottom for 1992) and right two panels are for low solar activity (the top for 1994 and the bottom for 1995).

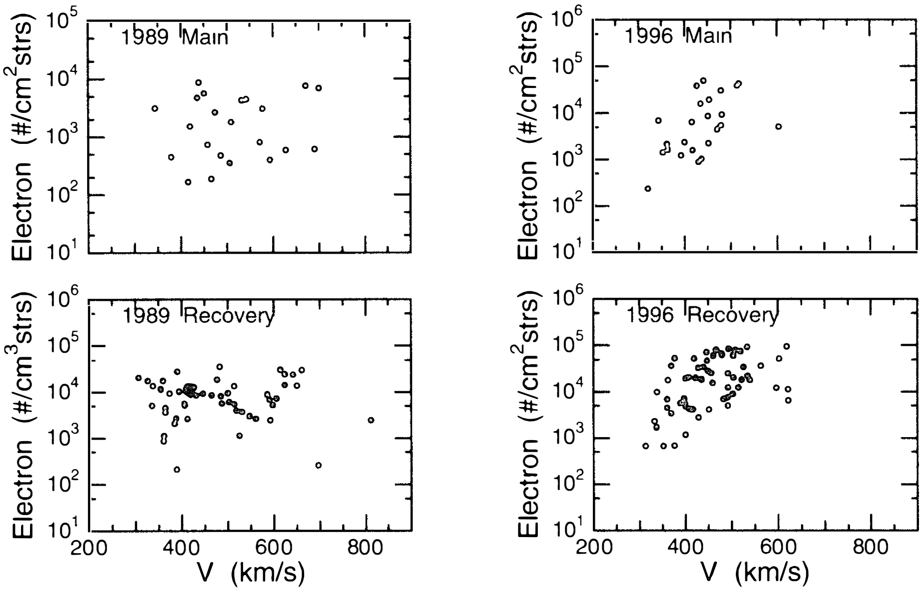

Fig. 6. Scatter plots in the same format as Fig. 3 for the main and recovery phases of a magnetic storm. The left two panels are for solar maximum; the top panel is for the main phase in 1989 and the bottom is for the recovery phase in 1989. The right two panels are for solar minimum; the top panel is for the main phase in 1996 and the bottom is for the recovery phase in 1996.

5. Discussion

Using data from ETS-V/DOM, we have found that the solar wind speed modulates the high-energy electron flux at geostationary orbit at solar minimum. We have also found that the correlation between the high-energy electron flux and the solar wind speed depends on solar activity. Although the correlation is clearly evident at solar minimum, none is apparent at solar maximum. This result suggests that high-speed streams from expanding coronal holes associated with recurrent geomagnetic storms contribute to the increase in high-energy electrons in the outer radiation belt. Sargent (1985) has demonstrated solar-cycle-dependent geomagnetic storms recurring every 27 days. Recurrent storms occur when the solar wind structure remains stable near solar minimum (Sargent, 1985). It is considered that, at solar maximum, non-recurrent magnetic storms caused by magnetic clouds, etc., frequently occur and hide the dependence of the electron flux on the solar wind speed.

We consider that the enhancement of electrons in the outer radiation belt is associated with some magnetospheric response to high-speed solar wind streams, *e.g.,* the ULF wave power. Li *et al.* (1998), by comparing the phase space density of solar wind electrons with magnetospheric electrons, have concluded that the high-energy electrons at geostationary orbit cannot simply be solar wind electrons transported from the solar wind. As seen in Fig. 5, we could not obtain clear correlations between the solar wind speed and the high-energy electron flux at geostationary orbit during the geomagnetically quiet period. This result suggests that enhancements of energetic electrons corresponding to fast solar wind streams at solar minimum require geomagnetic activity. Mathie and Mann (2000) have proposed that enhancements of the energetic electron flux during geomagnetic storms may depend on whether the associated solar wind speed leads to excitation of Pc5 waveguide modes by the magnetopause shear-flow instability based on the model by Mann *et al.* (1999). We must treat individually the dependence of the electron flux in the outer radiation belt on the solar wind speed by interplanetary conditions as the driver gas field and the sheath field. Solar wind effects are as large as effects of geomagnetic activity on the electron flux in the outer radiation belt. It is important, when considering the effect of geomagnetic activity on the variation of energetic electrons in the outer radiation belt, that the interplanetary condition, different at solar maximum and minimum, is taken into account. We have shown, however, only one case at solar minimum and maximum respectively, since the ETS-V/DOM data covers only one solar cycle. It is necessary to analyze a longer data series for confirmation of a statistical nature.

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