Simultaneous DMSP and CRRES Observation of Broadband Electrons During a Storm-Time Substorm on March 25, 1991

K. Shiokawa¹, R. R. Anderson², I. A. Daglis³, W. J. Hughes⁴ and J. R. Wygant⁵

¹Solar-Terrestrial Environment Laboratory, Nagoya University, Toyokawa 442, Japan
²Department of Physics and Astronomy, University of Iowa, Iowa City, IA 52242, U.S.A.
³Institute of Ionospheric and Space Research, National Observatory of Athens, 15236 Palea Penteli, Greece
⁴Department of Astronomy, Boston University, 725 Commonwealth Avenue, Boston, MA 02215, U.S.A.
⁵Tate Laboratory of Physics, University of Minnesota, 116 Church Street, SE, Minneapolis, MN 55455, U.S.A.

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Abstract. Broadband electrons observed by the DMSP satellites during storm-time substorms are characterized by an unusually intense flux of precipitating electrons over the broadband energy range from 30 eV to 30 keV near the equatorward edge of the auroral oval (Shiokawa et al., 1996; 1997). During the broadband electron event observed by the DMSP-F9 satellite at 21 MLT on March 25, 1991, the CRRES spacecraft was at a geocentric distance of 6.3 RE and in the same local time as that of DMSP. The CRRES satellite observed 1) a large enhancement of field-aligned electron flux, 2) highly turbulent electric fields up to 10 mV/m, 3) intense westward excursion (~100 nT) of magnetic field (suggesting intense field-aligned current generation) in a highly tail-like field configuration, 4) large O⁺ energy density, and 5) intense low-frequency (below 300 Hz) electrostatic waves. We discuss possible production mechanisms of broadband electrons on the basis of these observations.

1 Introduction

The broadband electrons exist as a common feature of precipitating electrons that appear associated with certain substorms during the main phase of magnetic storms. Although, it has been concluded that their magnetospheric source lies within the inner part of the plasma sheet (Shiokawa et al., 1997), their production mechanisms have not been identified yet. It is essentially needed to see plasma and field data in the magnetospheric source region of the broadband electrons. In this paper, we report a broadband electron event during which the DMSP and CRRES satellites are located in the same local time. We use CRRES data obtained by the magnetometer (Singer et al., 1992), the electric field instrument (Wygant et al., 1992), the low-energy plasma analyzer (LEPA) (Hardy et al., 1993), the magnetospheric ion composition spectrometer (MICS) (Wilken et al., 1992), and the plasma wave experiment (PWE) (Anderson et al., 1992). These data show various interesting characteristics of plasma and magnetic and electric fields around the source region of the broadband electrons.

2 Observations

Figure 1 shows the broadband electron event observed by the DMSP-F9 satellite on March 25, 1991. The broadband electrons were observed at magnetic latitudes (MLAT) from -55° (03:26:40 UT) to -58° (03:27:40 UT) in the premidnight sector at a magnetic local time (MLT) of 21.2 h. They are characterized by an intense flux of precipitating electrons at all energies measured (30 eV to 30 keV) around the equatorward boundary of the particle precipitation region. Ordinary plasma sheet electrons were observed poleward of the broadband electrons. Note that the poleward boundary of the broadband electrons (03:27:40 UT) is clearly defined at all energies.

The Dst variation during this storm is shown in Figure 2. The event of Figure 1 was observed during the main phase of an intense magnetic storm. The minimum Dst during the storm was -298 nT. The DMSP-F9 satellite crossed the same local time and latitude in the opposite hemisphere 30 min before the event and 70 min after the event. The satellite, however, did not observe any broadband electron features in these passes. A clear subauroral ion drift (SAID) was observed by the DMSP ion drift meter at equatorward of the broadband electrons, suggesting that the source of the electrons are in the inner part of the plasma sheet. These features are quite common for broadband electron events (see Shiokawa et al., 1997 for detail). A Pi 2-like magnetic pulsation is observed at ~0320 UT at midlatitude ground station, signaling a substorm onset.
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Fig. 1. Energy-time spectra (differential energy flux), energy fluxes, and average energies of precipitating ions and electrons observed by the DMSP-F9 satellite at 0323:45-0331:45 UT on March 25, 1991. Satellite locations are shown at the bottom of each figure, where MLAT, GLAT, GLON, and MLT are magnetic latitude, geographic latitude, geographic longitude, and magnetic local time, respectively. The satellite moved from lower latitudes to higher latitudes at an altitude of ~800 km. The broadband electrons are observed for 0326:40-0327:40 UT.

Fig. 2. Dst index during the magnetic storm of March 24-27, 1991. The vertical dashed line indicates the time when the broadband electrons shown in Figure 1 were observed by the DMSP-F9 satellite.

During this broadband electron event, CRRES was located at approximately the same local time to DMSP-F9 and measured plasma distributions, electric and magnetic fields, and plasma waves. Figure 3 shows the electric and magnetic fields and energy densities of H\(^+\) and O\(^+\) observed by CRRES on March 25, 1991 (orbit 590). The satellite was located close to the equatorial plane with a dipole magnetic latitude of 6°. The magnetic field shows highly tail-like configuration during the event. That is, the H (northward) component is only ~50 nT, while the V (outward) component is ~200 nT.

The D (eastward) component shows a large negative excursion of ~100 nT at the time around the event, suggesting that an intense field-aligned current is formed. The satellite was in the northern hemisphere, since the observed magnetic field was earthward. If an upward field-aligned current, which corresponds to the electron precipitation into the ionosphere, caused the observed D excursion, it can be concluded that the current was located earthward of the satellite.

The standard deviation of the electric field (second
panel in Figure 3) enhanced greatly at the time around the substorm onset (0320 UT). The maximum electric field variation reached up to 10 mV/m. The 30 s values of $E_p$ (duskward) and $E_n$ (northward) also varied strongly during the event. Similar fluctuations were also seen in the magnetic field data after 0320 UT. It is noted that no systematic dawn-dusk electric field was observed during the event.

As shown in the top panel of Figure 3, the energy density of O$^+$ was enhanced after the substorm onset at 0320 UT, while that of H$^+$ did not change. Note that the plotted time interval corresponds to the time when the contribution of the O$^+$ to the total energy density of the energetic ion population in the outer ring current region became maximum (more than 60%) during the storm of March 24-26, 1991 (Daglis, 1997).

Figure 4 shows energy-time spectra of electrons and ions perpendicular and parallel to the magnetic field observed by CRRES on March 25, 1991 (orbit 590). The satellite came from the evening sector at L~3 at 0100 UT and stayed in the premidnight sector around its apogee (L=6-7) for 0300-0700 UT. Just before the broadband electron event at 0327 UT, a drastic enhancement of electron fluxes was observed at energies up to 10 keV in both parallel and perpendicular directions. Note that the parallel enhancement was much stronger than the perpendicular enhancement. An enhancement of perpendicular ion flux was observed simultaneously at this time, while most of the ion flux at other time intervals and angular directions were below the one count level.

Figure 5 shows plasma wave intensity with frequencies of 5 Hz - 400 kHz observed by CRRES for the same time interval as that in Figure 4 (orbit 590). The enhanced Bernstein-mode electrostatic waves just above the cyclotron frequency (shown by the red line) were most evident from 0300-0530 UT. Enhanced Auroral Kilometric Radiation (AKR) at a frequency around 100 kHz was observed for 0300-0330 UT. This AKR intensification is probably associated with the substorm activity. The most striking feature in this figure is the very intense electrostatic waves at frequencies below 300 Hz between 0320 UT and 0400 UT. This feature is coincident with the broadband electrons observed by the DMSP satellite.

3 Summary and Discussion

Using data from the CRRES satellite, we have shown characteristics of plasmas and electric and magnetic fields in the equatorial plane at L=6.3 $R_E$ at the same local time sector as that of the broadband electrons. The broadband electrons took place associated with a substorm during the main phase of large magnetic storm on March 25, 1991. The observed characteristics are summarized as follows.

1. The magnetic field is in highly tail-like configuration at L=6.3 $R_E$ before and during the event.
2. Intense field-aligned current signature is observed in the east-west magnetic field component. Assuming an upward field-aligned current, the current region is located inside of L=6.3 $R_E$.
3. The electric field is highly turbulent with the maximum amplitude of $\sim$10 mV/m. No systematic dawn-dusk component is observed.
4. Large contribution of O$^+$ ions to the ring current is observed.
5. Electron flux is enhanced drastically at energies of 100 eV - 10 keV, particularly in the field-aligned directions. Perpendicular ion flux at energies above 8 keV is also enhanced.
6. Low frequency electrostatic waves below 300 Hz are strongly intensified.

During magnetic storms, the inner edge of the tail current sheet comes closer to the Earth due to the solar wind pressure enhancement (Siscoe and Cummings, 1969). The observed highly tail-like field at L=6.3 $R_E$ is probably because of this effect. It is likely that substorm processes in the tail also occur closer to the Earth under such conditions.

The observed turbulent electric field up to 10 mV/m is probably related to this substorm process. It is noted that no systematic dawn-dusk electric field is seen in the data. This fact suggests that the duskward electric field which causes earthward particle injection and energization during substorms cannot be the cause of the broadband electrons. This conclusion is also supported by the other fact that the enhancement of field-aligned electron fluxes is much larger than that of the perpendicular electron fluxes, since particle injection due to duskward electric field causes energization of the particles in perpendicular direction.

The intense low-frequency electrostatic waves below 300 Hz observed coincident with the broadband electrons are quite unusual even during the main phase of magnetic storms, since similar intense waves are not observed during the rest of CRRES orbit 590. These waves probably extend further to low frequency range in which the highly-turbulent electric fields up to 10 mV/m in Figure 3 is observed. These turbulent electric fields and waves may responsible for the generation of field-aligned electron fluxes and broadband electrons. Temerin et al. (1994) have discussed the particle acceleration by turbulent waves through Landau and cyclotron resonances in the ionosphere. It should be noted, however, that the poleward boundary of the broadband electrons is clearly defined at all energies, as shown in Figure 1. This is a common feature of the broadband electrons (Shiokawa et al., 1997). If one take the generation model of broadband electrons by turbulent waves, this boundary structure should be also explained.

Maynard et al. (1996) have shown particle characteristics observed by the CRRES satellite during the onset
Fig. 4. Energy-time spectra (differential number flux) of electrons and ions perpendicular (top panel) and parallel (bottom two panels) to the magnetic field and parallel (BgLC) and perpendicular (Bg90) background counts of electron and ion detectors observed by LEPA of the CRRES satellite on March 25, 1991 (orbit 590). The plotted energy range is between 100 eV and 30 keV. The designations of Earth and Earth indicate that LEPA was measuring particles moving away from the magnetic equator and the Earth, respectively. Fluxes are in cm$^{-2}$ s$^{-1}$ sr$^{-1}$ keV$^{-1}$. Satellite locations are indicated at the bottom, where GSMLT and L are local time and L-value, respectively.

Fig. 5. Plasma wave intensity (electric field) with frequencies from 5 Hz to 400 kHz observed by the CRRES satellite on March 25, 1991 (orbit 590). The wave intensity is shown in color codes in unit of dB V m$^{-1}$ Hz$^{-1}$ sr$^{-1}$. The red line indicates local cyclotron frequency. Satellite locations are indicated at the bottom of the panels, where R, MLAT, MLT, and L are radial distance, magnetic latitude, magnetic local time, and L-value, respectively.
of ordinary substorms. It is interesting to note that according to their observations the enhancement of perpendicular electron flux is always larger than that of parallel fluxes. The enhancement of field-aligned electron fluxes shown in this paper is different from their observations, while it is similar to that observed in the near-Earth neutral sheet at the onset of ordinary substorms by the AMPTE/IRM satellite (Shiokawa et al., 1998). It is quite difficult to determine whether this flux enhancement is related to the broadband electrons or not, since no magnetic field model can make realistic field-line tracing between DMSP and CRRES under such disturbed conditions. At least one can say that the observed particle characteristics at \( L=6.3 \) RE are similar to those observed in the near-Earth neutral sheet during ordinary substorms.

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References


