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LARGE AMPLITUDE ELECTROMAGNETIC FLUCTUATIONS IN THE INNER PLASMA SHEET REGION OBSERVED BY THE AKEBONO SATELLITE

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Abstract: We studied large amplitude electromagnetic fluctuations in the inner plasma sheet using magnetic field, electric field, and particle data obtained from the Akebono satellite. Only five large amplitude electromagnetic fluctuation events are found in the Akebono data set obtained in January and February 1990. These events occurred around 65° invariant latitude, having a narrow (~1 deg.) latitudinal width. In association with these fluctuations, field-aligned electrons and upward flowing ions are observed. The ground magnetic field variations near the satellite footpoint shows intensification and fluctuation of the westward electrojet during these events. Further, from the analysis of the amplitude and phase relationship between electric and magnetic fields, we conclude that these events are caused by superposition of incident and reflected Alfvén waves or traveling Alfvén waves. Our data analysis suggest that these large amplitude events are a transient process originating in the near-earth magnetotail region. It is possible that the energy source of this event is related to the substorm current system.

1. Introduction

The energy transfer between the magnetosphere and the ionosphere is important in the magnetospheric dynamics. Electromagnetic energies in the magnetosphere are transported to the ionosphere via field-aligned currents and Alfvén waves. Substorm is one of major phenomenon in energy release processes. In association with a substorm onset, magnetic field changes from tail-like to dipole-like configuration in the near-Earth magnetotail region. The dipolarization of magnetic field is due to a disruption of cross-tail currents (LUI, 1978). The cross-tail current diverts to flow into the ionosphere via field-aligned currents. This current system is often referred to as the substorm current wedge (MCPHERRON *et al.*, 1973). During the expansion phase of substorm, the current wedge expands toward both dawn and dusk sides, and the westward electrojet enhances in the ionosphere (*e.g.*, NAGAI, 1982). From the Akebono satellite data, we found large amplitude electromagnetic fluctuations in the inner plasma sheet region possibly related to the substorm current system. The origin of these fluctuations and their relationships to the development of substorm current system are studied.

2. Observations

In this paper, electric and magnetic field and low energy particle data obtained from the Akebono satellite are used (FUKUNISHI *et al.*, 1990; HAYAKAWA *et al.*, 1990; MUKAI *et al.*, 1990). Figure 1 shows an example of the large amplitude electromagnetic fluctuations in the inner plasma sheet region observed by the Akebono satellite on February 4, 1990. The top four panels represent energy-time and pitch angle-time diagrams for electrons and ions, respectively. The fifth panel represents electric field X, Y, and Z components based on the GSM coordinate system. The sixth panel shows the geographical east-west and north-south components of the perturbation magnetic field. The bottom panel shows current densities estimated from magnetic field data without assuming the L shell alignment. Detailed description of this method was presented by FUKUNISHI *et al.* (1993). Satellite location is indicated at the bottom. In this case, Akebono satellite moves from high to low latitudes in the midnight sector. Polar cap boundary of the plasma sheet is identified from the poleward termination of the plasmasheet-like electrons observed at 2002 UT. Velocity dispersed ion signature is observed at 2003 UT. These signatures suggest that this region is mapped to the plasma sheet boundary layer (PSBL). Intense field-aligned currents and electric field fluctuations are firstly seen from 2007 to 2009 UT. Suprathermal electrons are observed from 2004 UT. Weak flux of upward flowing ions (UFIs) are occurred from 2007 to 2009 UT. These are the typical signature seen in the poleward boundary region of the nightside auroral oval (FUKUNISHI *et al.*, 1993; NAGATSUMA *et al.*, 1996). Further, another large amplitude electromagnetic fluctuations are observed simultaneously with the suprathermal electron beams and UFIs from 2013 to 2016 UT. In this paper, we defined these fluctuations as "large amplitude event". The important point of this event is the occurrence location; the large amplitude event is observed around 65° invariant latitude. And the occurrence location of this event is separated from the poleward boundary of the nightside auroral oval. These signatures suggest that the location of this event is mapped not to the PSBL but to the inner plasmasheet region. The maximum amplitude of the electric field fluctuation is 100 mV/m, and current density is 5 μA/m^2. Field-aligned suprathermal electrons and UFIs are enhanced there in comparison with those observed in the poleward boundary region. The large amplitude event occurred within the localized region (~1 deg.), although we cannot identify the width of the particle signature, because low energy particle instrument was turned off at 2016 UT. The occurrence of this type of event is rare, while the large amplitude electric and magnetic field fluctuations are frequently observed in the poleward boundary region. We find 5 events from Akebono observations during January to February 1990.

Next, we compare Akebono observations with ground magnetic field variations. The trajectory of Akebono satellite projected to the ionospheric altitude of 120 km are shown in Fig. 2. The Akebono satellite traversed Scandinavian region in this case. Locations of the EISCAT magnetometer stations are shown in this figure (LÜHR *et al.*, 1984). The occurrence region of the large amplitude event is plotted with a thick line. The large amplitude event is observed while the footpoint of the satellite moves near MUO station.

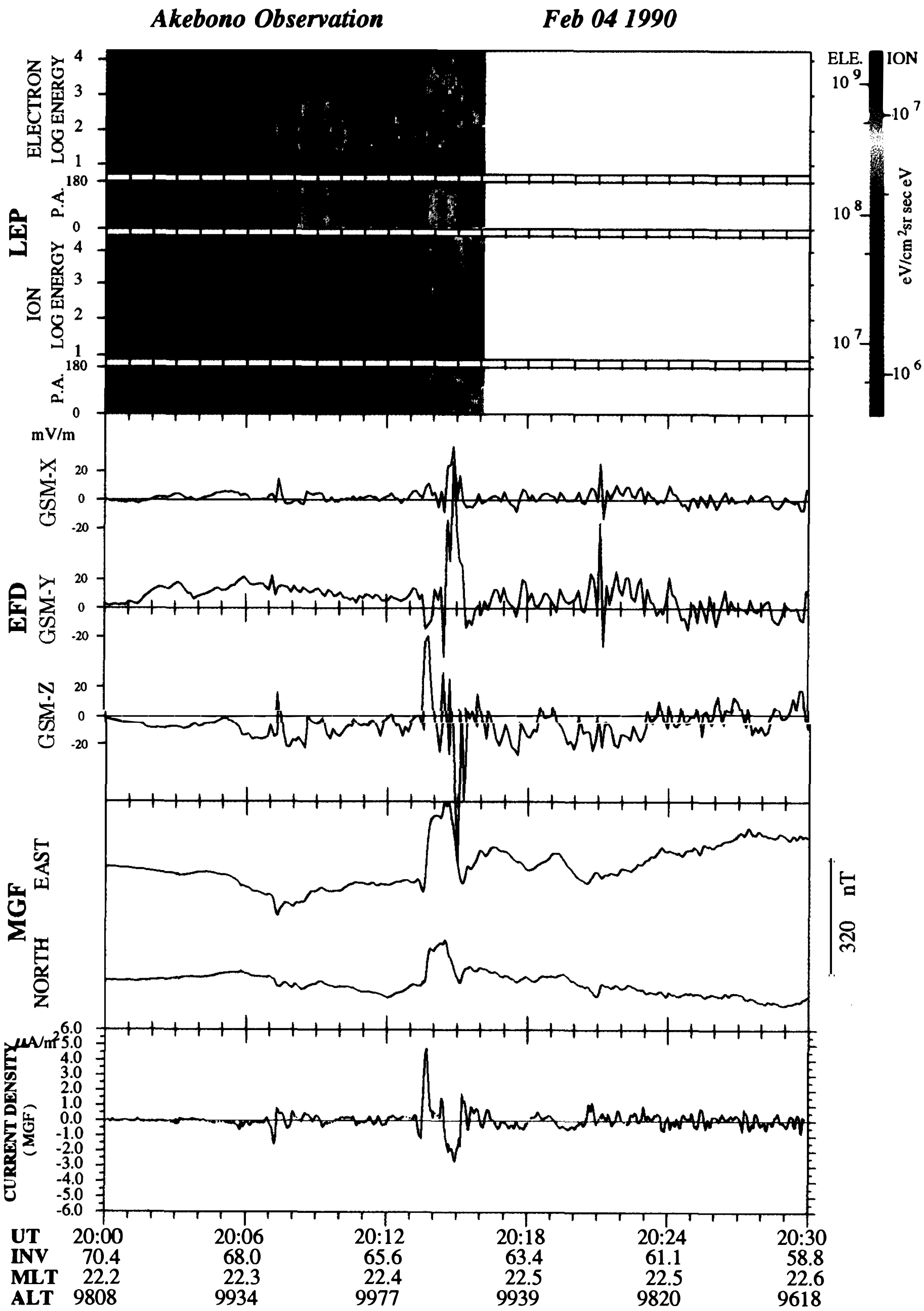

Fig. 1. Magnetic and electric fields and charged particles data in the nightside auroral oval observed by the Akebono satellite on February 4, 1990. The top four panels represent energy-time spectrograms and pitch angle time diagrams for electrons and ions, respectively. The fifth panel represents electric field X, Y, and Z components in the GSM coordinate system. The sixth panel indicates the geographical east-west and north-south components of the perturbation magnetic field. The bottom panel shows current densities estimated from magnetic field data. The satellite locations are given at the bottom.

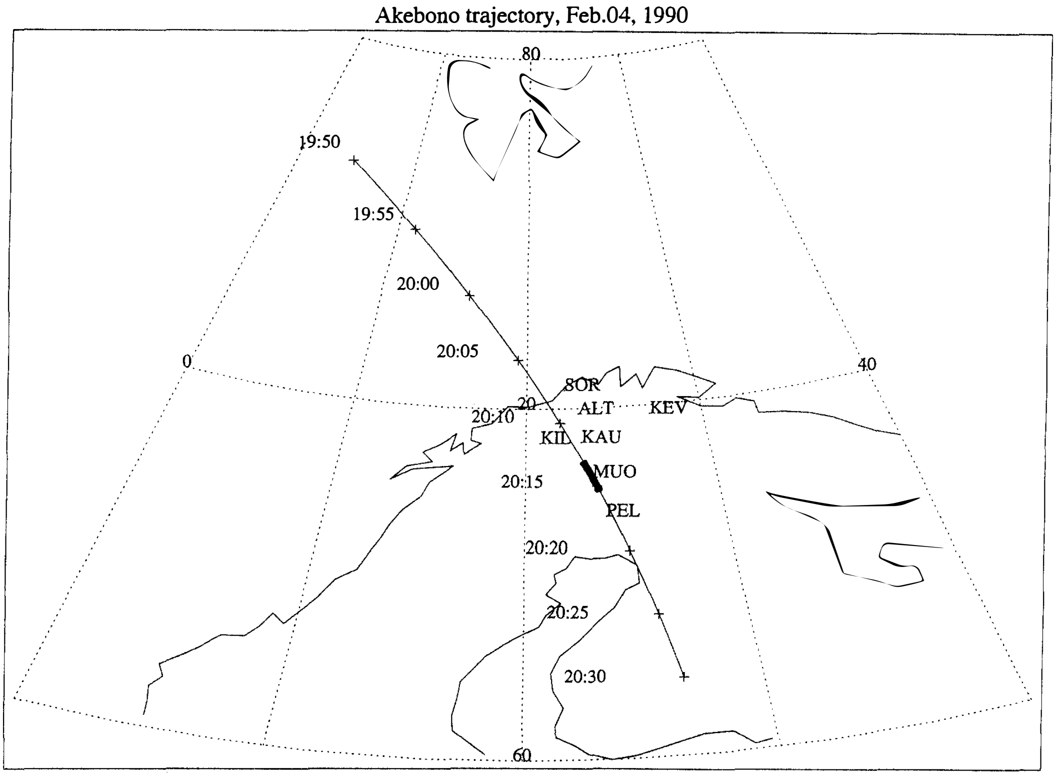

Fig. 2. Orbital trajectory of the Akebono satellite on February 4, 1990. The trajectory are mapped along the magnetic field line to the ionospheric altitude of 120 km. The occurrence region of the large amplitude event is plotted with a thick line. Locations of the EISCAT magnetometer chain stations are also shown in this figure.

Figure 3 shows X and Z components of the EISCAT magnetometer chain data. The time resolution of these data is 20 s. At all stations of this chain, X component of magnetic field gradually decreased from about 1946 UT. At 2012 UT, the X component suddenly decreased at KEV, KIL, KAU, MUO, and PEL almost simultaneously, while some delayed decreases were seen at ALT and SOR. The variation of the Z component at MUO was rather small compared to the other stations. The higher latitude stations observed larger increase of Z component. And the lower latitude station, PEL observed decrease of Z component at 2012 UT. After the sudden decrease, the X component of the magnetic field fluctuated for several minutes. The large amplitude event was observed during this time period. From the comparison between EISCAT magnetometer chain and Akebono satellite magnetic field data, it is found that all five large amplitude events took place with the decrease and fluctuation of the X component of the ground magnetic field data.

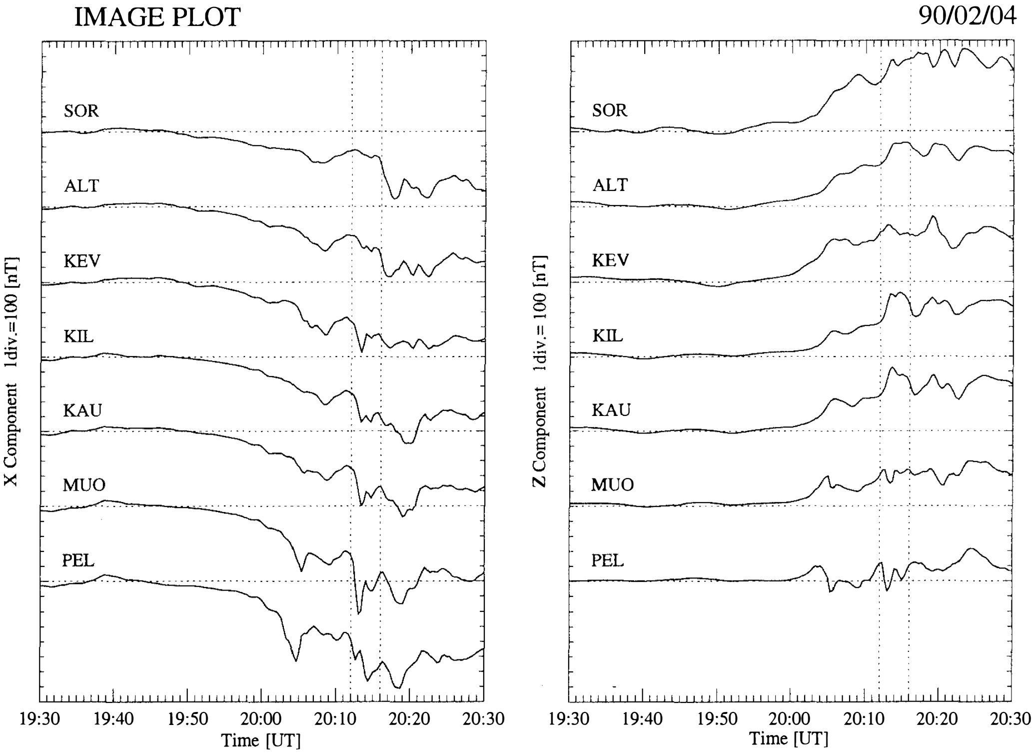

Fig. 3. X component (left) and Z component (right) of magnetic field data from the EISCAT magnetometer chain on February 4, 1990.

3. Summary and Discussion

Characteristics of the large amplitude electric and magnetic field fluctuations and their relationships to the ground magnetic field variations are shown in the previous section. To identify whether space structure or time variations are dominant at these fluctuations, we calculated complex impedance function from the electric and magnetic field data and compared them with model impedance functions. The complex impedance function $\tilde{Z}$ is given by $\tilde{Z}=\mu_0\tilde{E}_y/\tilde{B}_x$, where $\tilde{E}_y$ and $\tilde{B}_x$ are complex Fourier transforms of $\tilde{E}_y$ and $\tilde{B}_x$, respectively, and μ_0 is the permeability in a vacuum. KNUDSEN *et al.* (1990, 1992) and NAGATSUMA *et al.* (1996) attempted to examine the origin of the electric and magnetic field fluctuations through this method. The following two cases are considered in this paper:

Case 1: A static M-I coupling ($\tilde{Z}_{\mathrm{static}}$)

$$\tilde{Z}_{\mathrm{static}}=\Sigma_P^{-1}, \tag{1}$$

where Σ_P is the height-integrated Pedersen conductivity.

Case 2: A time-dependent M-I coupling due to Alfvén waves ($\tilde{Z}_{\mathrm{wave}}$)

$$\tilde{Z}_{\mathrm{wave}}(f, z)=\Sigma_A^{-1}\left[\frac{1+\Gamma\exp(-4\pi ifz/V_A)}{1-\Gamma\exp(-4\pi ifz/V_A)}\right], \tag{2}$$

where f is the wave frequency, z is the distance from the reflection point at the ionosphere to the satellite altitude, and V_A is the Alfvén velocity. The Alfvén conductance Σ_A and the reflection coefficient Γ are defined as follows:

$$\Sigma_A = (\mu_0 V_A)^{-1}, \tag{3}$$

$$\Gamma = \frac{\Sigma_A - \Sigma_P}{\Sigma_A + \Sigma_P} . \tag{4}$$

Here it is assumed that V_A is constant along the field line and the ionosphere behaves as a slab reflector.

The impedance function was calculated from north-south component of electric field (E_y) and east-west component of magnetic field (B_x) from 2013:20 to 2017:32 UT on February 4, 1990. The time resolution of electric and magnetic field data is 8 s. For our model calculation, Σ_P is estimated from particle data from Akebono satellite using empirical formula (ROBINSON *et al.*, 1987). From particle data, the averaged Σ_P during this period is estimated to be 9.5 mho. V_A is assumed to be 12000 km/s from our previous work (NAGATSUMA *et al.*, 1996).

The results of the spectral analysis are shown in Fig. 4. The top panel shows power spectrum of E_y and B_x. Thin and thick lines show power spectrum of E_y and B_x, respectively. Second panel shows the amplitude component of the complex impedance function ($|\tilde{Z}|$). Observed impedance function ($|\tilde{Z}_{obs}|$) is indicated by thick line. Static and wave model impedance functions ($|\tilde{Z}_{static}|$ and $|\tilde{Z}_{wave}|$) are indicated respectively by dotted and dashed line. Third panel shows the phase component of the complex impedance function ($\arg(\tilde{Z})$). Coherence spectrum between E_y and B_x are shown in the bottom panel. The impedance at the lower-frequency limit is found to be 0.33 Ω. The impedance is higher compared to the inverse of the Pedersen conductivity. And the amplitude of the impedance increases with frequency. The phase difference between E_y and B_x is near $\pi/2$ in the frequency range below 0.034 Hz. Both amplitude and phase component of $\tilde{Z}_{obs}$ is well explained by the Alfvén wave model. High reflection coefficient ($\Gamma = -0.98$) shows that these electromagnetic fluctuations are due to the superposition of incident Alfvén waves from the magnetosphere and reflected waves from the ionosphere (NAGATSUMA *et al.*, 1996). These characteristics and the results of data analysis suggest that the large amplitude event is a transient process connected to the near-earth magnetotail region. However, impedance function of some other event shows high impedance but no phase shift. These signatures are due to traveling Alfvén wave from the magnetosphere. The difference between these two types of events might be related to the non-uniformity of the ionospheric conductivity and the time variation of the Alfvén waves is quite rapid and cannot form standing Alfvén wave signature.

Next, the relationship between large amplitude event and the variation of the ground magnetic field is discussed. The magnetic field variations observed on the ground is caused by current flowing in the ionosphere. The model calculation shows that in the case of the westward ionospheric current flown within a narrow latitudinal width, the maximum decrease of the X component is observed just under the current center. And Z component increase at the higher latitude side and decrease at the lower latitude side on the ground and no variations just under the current center (*e.g.*,

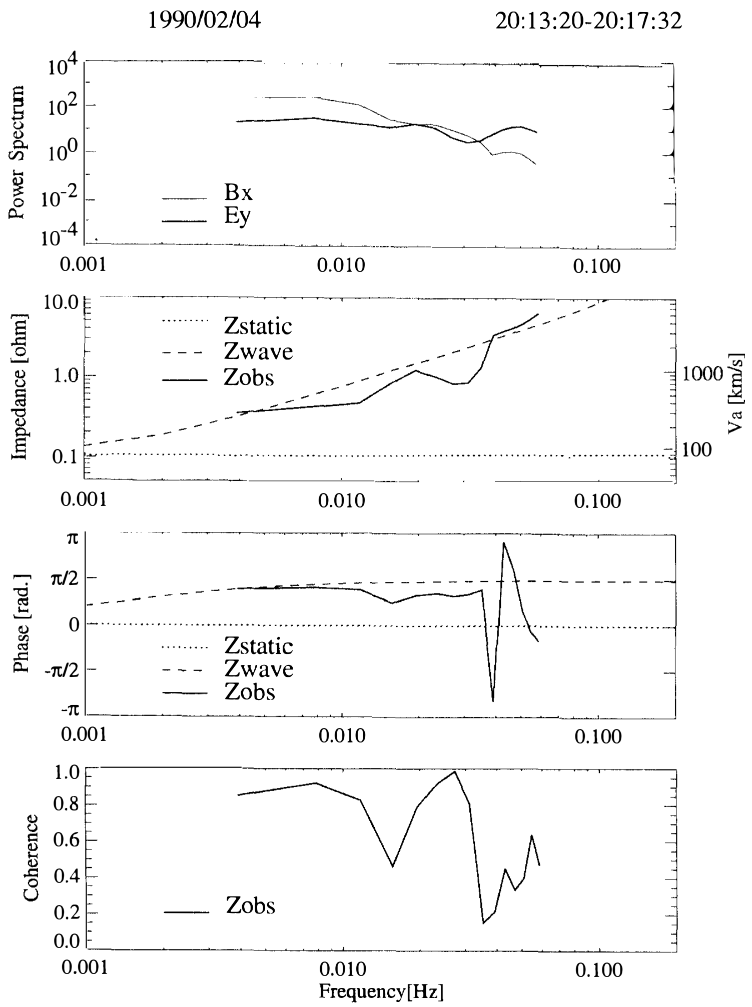

Fig. 4. Power and impedance spectra estimated from electric and magnetic field variations observed by the Akebono satellite during the large amplitude event on February 4, 1990. Top panel: Power spectra of E_y(north-south) and B_x(east-west). Second panel: the amplitude component of the complex impedance function($|\tilde{Z}|$). Third panel: the phase component of the complex impedance function($\arg(\tilde{Z})$). Bottom panel: coherence between E_y and B_x. Characteristics of amplitude and phase of the impedance shows that these fluctuations are due to superposition of incident Alfvén waves from the magnetosphere and reflected waves from the ionosphere.

KISABETH and ROSTOKER, 1971). Considering the results of this calculation, the X and Z component magnetic field variations at 2012 UT suggests that the center of the current exists near above MUO. Simultaneous occurrence of the large amplitude event and enhancement and fluctuation of the westward electrojet suggests that those two events are correlated each other.

Finally, energy source of the large amplitude event is discussed. As shown in the previous section, the large amplitude events are associated with the sudden decrease and fluctuation of the X component of the magnetic field. The decrease of the X component is interpreted to be due to the intensification of the westward electrojet related to the substorm activity. In the case of this event, the substorm onset identified from the Pi 2 activity of SAMMET magnetometer data is 1959 UT. High energy particle data from LANL satellite (1984-129) shows non-dispersed injection at 1959:50 UT (These data are not shown here.). Thus, the substorm onset is occurred close to the LANL satellite meridian. The magnetic local time of 1984-129 is 1.5 MLT, and the local time difference between 1984-129 and Akebono satellite is about 3 hours. NAGAI (1991) showed that the delay time of local dipolarization onset in the local time difference of 3 hours was about 10 min. Therefore, about 10 min after the substorm onset (1959 UT), that is around 2009 UT, the substorm current system reached at the Akebono meridian. It is possible that the development of the substorm current system excited a large amplitude event. The relationship between large amplitude event and ground magnetic field fluctuations support this idea.

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