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WHERE IS THE CURRENT DISRUPTION SET UP? (EXTENDED ABSTRACT)

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It has been widely accepted that a substorm expansion phase onset is accompanied by an onset of ground Pi 2 pulsations, and at the onset of ground Pi 2 pulsations observed at the dip-equator, magnetic field changes are often detected at nightside geosynchronous orbit. Using high-time resolution magnetic field data from the geosynchronous satellite GOES 5 (from March 1 to June 20, 1986), we examined the dynamic field changes in the nightside magnetosphere.

The field perturbations occurred in the midnight sector of the magnetosphere are divided into two modes: the poloidal and toroidal modes. We will first examine the differential equations describing the poloidal and toroidal modes, respectively. The following equations have been obtained from momentum equation and Maxwell's equation.

$$\left\{\rho_{m0}\omega^2+\frac{1}{\mu_0}\left(B_0\frac{\partial}{\partial z}\right)^2\right\}\xi_{n\perp}=\nabla_{n\perp}\left(\delta p_\perp+\frac{B_0\delta b_z}{\mu_0}\right)+\frac{n}{R}\left(\delta p_z-\delta p_\perp-\frac{2B_0\delta b_z}{\mu_0}\right), \quad (1)$$

$$\left\{\rho_{m0}\omega^2+\frac{1}{\mu_0}\left(B_0\frac{\partial}{\partial z}\right)^2\right\}\xi_{\Phi}=\nabla_{\Phi}\left(\delta p_\perp+\frac{B_0\delta b_z}{\mu_0}\right). \quad (2)$$

Figure 1 is illustration of the orientation relative to vector aligned coordinates (n, Φ, z), where z is directed along the field lines, n is normal to the field line pointing

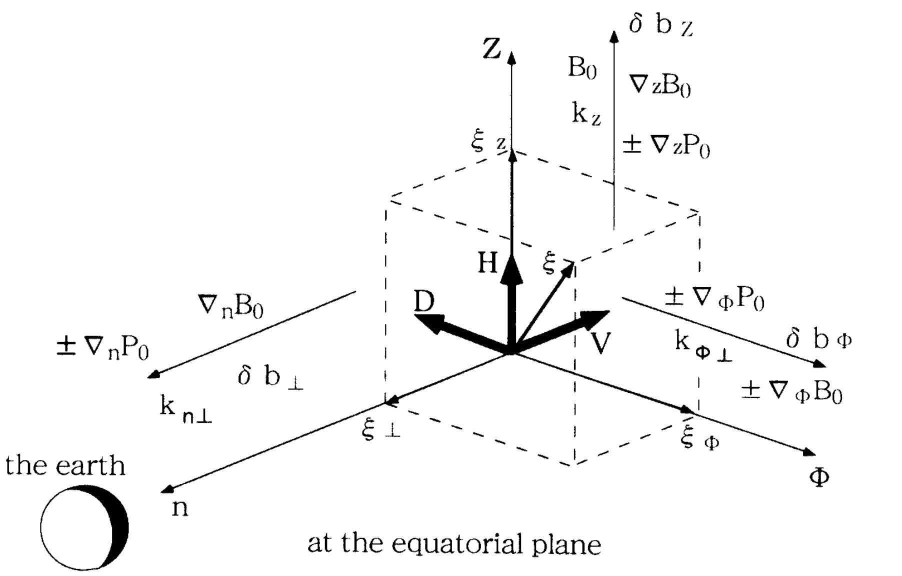

Fig. 1. Orientation relative to the coordinates (n, Φ, z) and the dipole coordinates (V, D, H) of on the nightside equotorial plane.

inwards and Φ is the azimuthal direction ($z=n\times\Phi$), of some vectors on the nightside equatorial plane at a substorm onset. Here, B_0 is the ambient magnetic field, δb is the field perturbation, P_0 is the ambient plasma pressure, δp is the plasma pressure perturbation, ξ is the field line displacement, k is the wave number vector, ρ_{m0} is the ambient plasma mass density, μ_0 is the magnetic permeability of free space, and R is the field line radius of curvature. And the suffix 'z' and '$\perp$' stand for the component 'parallel' and 'perpendicular' to B_0 at the equatorial plane in the magnetosphere, respectively. ∇P_0 and $\nabla_\Phi B_0$ are introduced not to neglect terms which include them. Equation (1) describes the poloidal mode, on the other hand eq. (2) describes the toroidal mode. The r.h.s. of eq. (1) indicates that the temporal and spatial development of the poloidal mode depends on total pressure ($\delta p_\perp + B_0\delta b_z/\mu_0$) and field line curvature. The r.h.s. of eq. (2) indicates that the temporal and spatial development of the toroidal mode depends on total pressure alone, in other words, the toroidal mode does not depend on a slow magnetosonic wave which holds $\delta p_\perp + B_0\delta b_z/\mu_0=0$, but on a fast magnetosonic wave. NOSÉ *et al.* (1998) examined statistically the azimuthal magnetic pulsations on the nightside, which they consider as the same phenomena as TTW (transient toroidal waves; see TAKAHASHI *et al.*, 1996) and QPO (quasi-periodic oscillations; see SAKA *et al.*, 1996), and concluded that the azimuthal magnetic pulsations on the nightside are

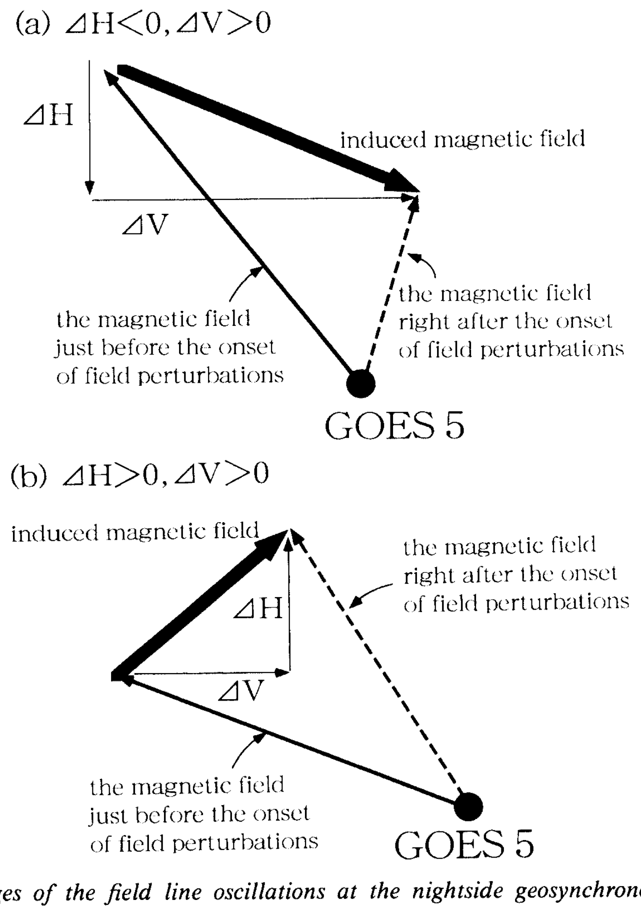

Fig. 2. Initial changes of the field line oscillations at the nightside geosynchronous orbit at substorm onset. The upper figure (a) is for $\Delta H<0$ and $\Delta V>0$, and the lower one (b) is for $\Delta H>0$ and $\Delta V>0$.

excited through coupling to the fast mode Alfvén waves which are radiated at substorm onsets. We suggest that our interpretation of eq. (2) supports the mechanism proposed by NOSÉ *et al.* (1998). Anyway, in both equations, the r.h.s. shows that sources of the field perturbations occurred in the midnight sector of the magnetosphere are the magnetosonic waves which were launched at substorm onset (see LUI, 1996). Then where are the magnetosonic waves launched? The answer is thought to be in the feature of the first field change in the magnetosphere. In the present paper, for simplicity, we shall confine our attention to the magnetic field changes of H and V components. Hereafter, the dipole coordinates (V, D, H) (V is outward, D is azimuthally eastward, and H is along the dipole axis; see Fig. 1) are used for the satellite data because δb_z in the r.h.s. of eqs. (1) and (2) is parallel to the dipole axis and we want to examine the first field change that is a direct response of δb_z, though the dipole coordinates (V, D, H) are different from vector aligned coordinates (n, Φ, z).

With reference to a substorm expansion phase onset, magnetic field data (H component) at Huancayo which is in the same meridian of GOES 5, during about 4 months from March 1 to June 20, 1986 were analyzed and selected 56 Pi 2 events by both band pass filter (40–150 s) and visual inspection. Then, for the 56 events, the clear onsets of the magnetic field perturbations at the geosynchronous satellite GOES 5 on the nightside were searched, and 41 events were also identified by both band pass filter (40–150 s) and visual inspection. We found that these 41 events may be roughly divided into following two types of the initial change of the field perturbations; ① H component decrease and V component increase, and ② H component increase and V component increase. For these two types, the relative orientations of magnetic field vectors are

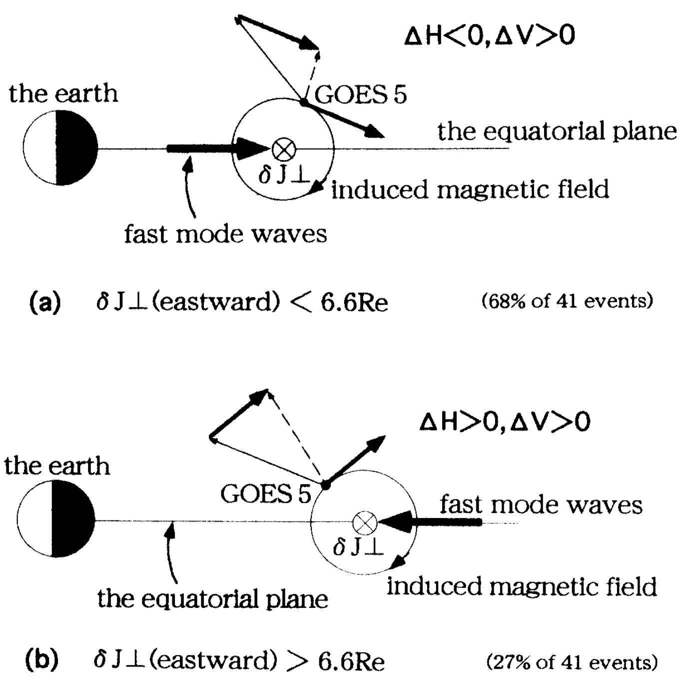

Fig. 3. Schematic diagrams depicting the position of the eastward cross-tail current perturbation which is set up at substorm onset. Figure 3a corresponds to Fig. 2a (namely, $\Delta H<0$ and $\Delta V>0$ at substorm onset). Figure 3b corresponds to Fig. 2b (namely, $\Delta H>0$ and $\Delta V>0$ at substorm onset).

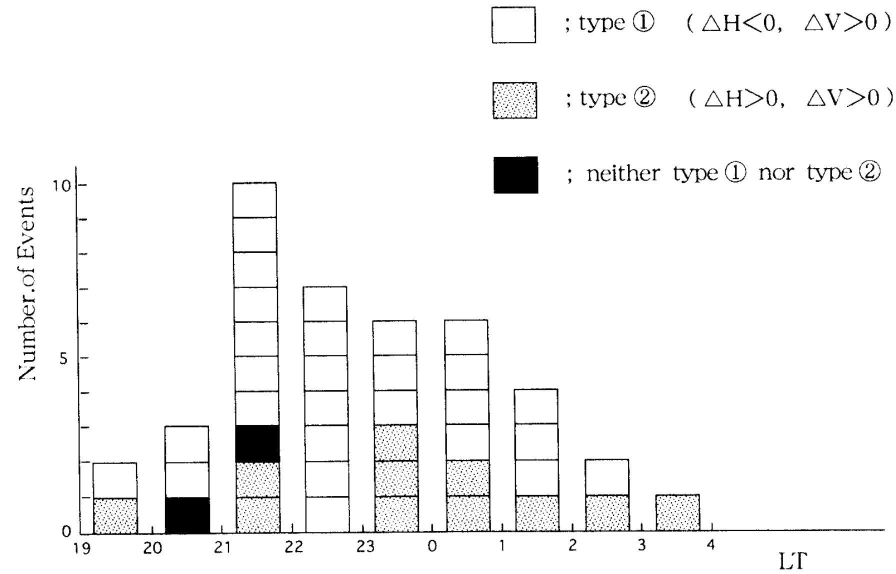

Fig. 4. Local time distribution of the 41 magnetic field perturbation events. Type ① (namely, $\Delta H < 0$ and $\Delta V > 0$ at substorm onset) events and type ② (namely, $\Delta H > 0$ and $\Delta V > 0$ at substorm onset) events are represented by white blocks and dotted blocks, respectively. The events represented by black blocks are neither type ① nor type ②.

illustrated in Fig. 2. The upper figure (a) is for ①, and the lower one (b) is for ②. Let us add the cross-tail current perturbation $\delta J_\perp$ which was on the fast mode wave front and induced the initial magnetic field changes to these figures (see Fig. 3). Figure 3a corresponds to Fig. 2a (namely, $\Delta H < 0$ and $\Delta V > 0$ at substorm onset). The important point to note is that $\delta J_\perp$ (eastward) is inside the geosynchronous altitude ($6.6\,R_E$). Figure 3b corresponds to Fig. 2b (namely, $\Delta H > 0$ and $\Delta V > 0$ at substorm onset), and $\delta J_\perp$ (eastward) is outside the geosynchronous altitude. Of the 41 magnetic field perturbation events mentioned above, 27% of them were recognized as type ② (see Fig. 3b), 68% as type ① (see Fig. 3a), and 5% were neither type ① nor type ② (see Fig. 4). This result shows that type ① is the majority. Judging from this observed fact, it may be concluded that the current disruption which radiates the magnetosonic waves occures more frequently inside the geosynchronous altitude ($6.6\,R_E$) at substorm onset.

Let us now remember the 'standard' substorm model, for example, the near-Earth neutral line model (BAKER and PULKKINEN, 1991). In the standard model, the expansion phase begins when a near-Earth neutral line is formed at $\sim 15\,R_E$ geocentric distance. On the other hand, as we have mentioned before, most current disruption take place inside $6.6\,R_E$. With magnetic field data obtained from ISEE-1($-11.3\,R_E$) and ISEE-2($-12.8\,R_E$) both at 01 MLT, JACQUEY *et al.* (1993) suggested that the disruption starts at 6–9 R_E and propagates down the tail with a velocity of the order of 150 to 250 km/s over tens of earth radii during the substorm expansion phase, although they did not suggest what carries the tailward propagating disruption. This result that most of current disruptions take place inside $6.6\,R_E$ admits of two interpretations. One explanation may be that current disruptions are caused by an inertia current due to earthward flow from outside $6.6\,R_E$. If the earthward flow reaches and slows down inside $6.6\,R_E$, one may say that the inertia current is generated inside $6.6\,R_E$, although it is not certain whether $\delta J_{\perp}$ on the fast mode wave front is eastward. SHIOKAWA *et al.* (1998) concluded that a substorm current wedge is caused by an inertia current and the current due to flow shear at braking point of an earthward high-speed ion flow, though they suppose that the braking point will be formed at 10–20 R_E. The other explanation may be that 'something' causing the current disruption is inside of 6.6 R_E, namely, that substorm expansion phase onset condition is set up inside 6.6 R_E. If 'something' is analogically not a resistor but, for example, a battery, or a condenser in a circuit, $\delta J_{\perp}$ on the fast mode wave front can be eastward. We need to consider H, V, D as a whole to clarify this problem in the future.

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