VIKING OBSERVATION OF THE SUBSTORM CURRENT WEDGE

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ABSTRACT

The current system during substorm expansive phases is studied using Viking data and the AE index for the morning sector. A pair of strong field-aligned currents is often observed within the boundary plasma sheet together with a weak region 2 field-aligned current in the central plasma sheet plasma. That indicates that the current wedge is composed of a closely-located pair of field-aligned currents rather than a single downward (or upward) current. This observation is consistent with the expanding current wedge model based on the MHD fast mode dynamo theory.

Keywords: MHD waves, Current Wedge, Expansive Phase, Field-Aligned Current.

1. INTRODUCTION

Recently, one of the authors proposed a theory of MHD fast mode dynamo (Ref. 1), which is applicable to both dayside (the cusp current system) and nightside (the substorm current system). The theory implies, for example, that the substorm current wedge is composed of two pairs of field-aligned currents (FACs), one pair in the premidnight sector and the other pair in the postmidnight sector, which are closed by a dusk-to-dawn disruption current as well as longitudinal polarization currents in the near earth plasma sheet. The proposed current system is illustrated in Figure 1. Details of the MHD fast mode dynamo theory can be found in another paper (Yamauchi M 1992, "MHD fast mode dynamo and its application to the substorm current system," submitted to Ann. Geophys.; hereafter referred to as "paper 1"). Here, we briefly review the theory, and then show a supporting observational evidence.

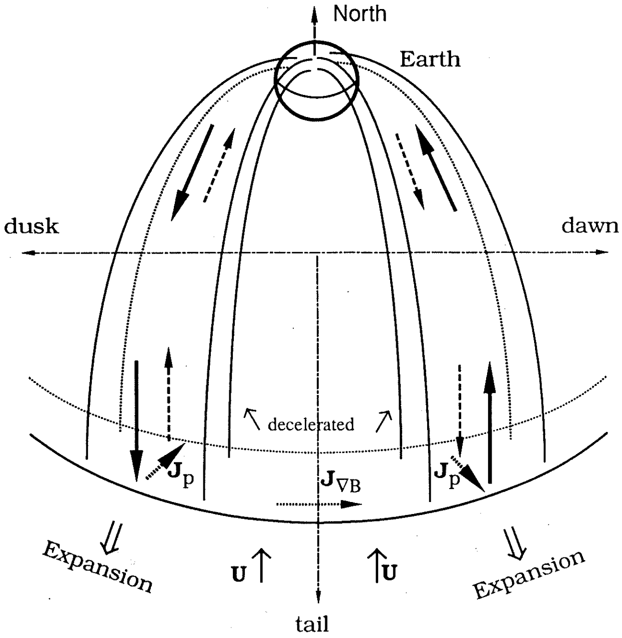
2. MODEL

2.1 *MHD Fast Mode Dynamo*

We consider an MHD fast mode disturbance propagating against a rather fast convection, and electric charge accumulation due to this disturbance in a limited area in the magnetosphere. The fully non-linear form of the MHD vorticity equation is well known (Refs. 2, 3) as:

$$\frac{d}{dt}\left[\frac{\nabla_\perp\cdot\mathbf{E}_\perp - (\mathbf{U}_\perp\times\nabla_\perp\mathbf{B})_{//}}{B^2}\right] = \frac{\nabla_\perp\cdot\mathbf{J}_\perp}{\rho} \qquad (1)$$

where we used the MHD fast mode condition $\nabla(B/\rho) = 0$ and the



$\mathbf{J}_p$: polarization current

$\mathbf{J}_{\nabla B}$: surface current of MHD fast wave

U : enhanced convection

Fig. 1: Proposed overview of the substorm current wedge based on the MHD fast mode dynamo theory (from paper 1). Two pairs of field-aligned currents (FACs) are linked to a dusk-to-dawn disruption current and longitudinal polarization currents in the plasma sheet. The whole current system expands tailward (= poleward in the ionosphere) against an enhanced magnetospheric convection. The upward FACs accounts for the discrete aurora for both premidnight and postmidnight sectors.

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frozen-in condition $\mathbf{E}_\perp = -\mathbf{U}\times\mathbf{B}$. This equation describes how the space charges ($\propto\nabla\cdot E$) are given by the perpendicular current ($J_\perp$) and the overall configuration (∇P and $\mathbf{U}$). The accumulated space charges flow out of the source region along the geomagnetic field as Alfvén waves satisfying the following relation

$$h\,\nabla_\perp\cdot\mathbf{J}_\perp = -\,\Sigma_A\,\nabla_\perp\cdot\mathbf{E}_\perp \qquad (2)$$

where h is the thickness of the source region, $\Sigma_A = (\mu_0 V_A)^{-1}$ is the Alfvén wave conductivity (Ref. 4), and V_A is the Alfvén velocity. Substituting (2) into (1), we finally have

$$\left(\frac{1}{\tau}+\frac{d}{dt}\right)\frac{\nabla_\perp\cdot\mathbf{E}_\perp}{B^2} = \frac{d}{dt}\frac{(\mathbf{U}_\perp\times\nabla_\perp B)_{//}}{B^2} \qquad (3)$$

eq (3) detail = doi.org/10.1029/93JA00638

where $\tau = \rho h/(\Sigma_A B^2)$ is the decay time which represents how efficiently the separated space charge is carried away by the Alfvén wave. This decay term comes from the $\nabla_\perp\cdot\mathbf{J}_\perp$ term of equation (1).

Equation (3) is a first order differential equation for the space charge, and hence, for the field-aligned current. It states that we may have FACs if the fluid element experiences a change of $\mathbf{U}_\perp \times \nabla_\perp\mathbf{B}$. This source term has been neglected from linear studies in which the convection is assumed to be slow; however, it can be substantially important when the magnetospheric convection is enhanced during substorms. Since $\mathbf{U}_\perp \times \nabla_\perp\mathbf{B}$ must be zero or otherwise very small in both the upstream side and the far downstream side, non-zero $\mathbf{U}_\perp \times \nabla_\perp\mathbf{B}$ inside the disturbance means that its spatial derivative (d/dt term means a spatial derivative in a quasi-steady state) should have at least both a positive value and a negative value somewhere. Thus, we have a pair of plus and minus values for the source term of (3), and hence, a solution of equation (3). This solution guarantees two pairs of the FACs in the premidnight and postmidnight sectors which are closed with the polarization current ($\mathbf{J}_P$) as shown in Figure 1.

Figure 1 contains one more current system which includes the dusk-to-dawn current ($\mathbf{J}_{\nabla B}$). This is the ordinary current which always appears in the MHD fast wave, but its divergence toward the earth is due to the finite extend (2-D effect) toward dawn and dusk. This system is the same as the traditional substorm current wedge. This overall configuration of Figure 1 is also obtained from numerical simulations (Ref. 1). A more detailed discussion can be found in paper 1.

2.2 *Expanding Substorm Current Wedge*

In many substorm related phenomena, we often have to consider the magnetosphere-ionosphere coupling; i.e., the effect of reflected Alfvén waves from the ionosphere. However, the source region moves further upstream across the geomagnetic field with the MHD fast mode velocity before the reflected Alfvén wave comes back to the magnetosphere, and the reflected wave never catches up with the source region. Therefore, we may neglect the reflected wave in the present case.

Figure 1 explains many phenomena associated with the substorm expansive phase. For example, disruption of the cross tail current and related dipolarization (Ref. 5), tailward propagation of such disturbance against the convection (Ref. 6), related poleward leap of discrete aurora for both premidnight and postmidnight sectors (Ref. 7) which is the main improvement of this model from the single current wedge model (Ref. 8), and the fact that dispersionless plasma injection precedes the initial dipolarization (Ref. 9) are all explained by the present semi-double current wedge model.

One thing we have to examine is the double current structure, which is the most peculiar feature of the present model. The model predicts that the FACs should be observed as a pair with less intense current on the downstream (equatorward) side. Here, we examine it using Viking data for the postmidnight sector during the substorm expansive phase. For the premidnight sector, readers are referred to another paper in this volume (Ref. 10).

3. OBSERVATION

Figure 2 shows a Viking energy-time particle spectrogram and magnetic field data from orbit 1402 and the corresponding AE index. The AE index shows that the pass occurred as the end of a substorm expansive phase. There are four distinctive regions labelled *a-d* in the figure. Region *a* is a polar arc (1828-1829 UT) that carries very little FACs. Regions *b* and *c* are both within the boundary plasma sheet (BPS); however, FACs are

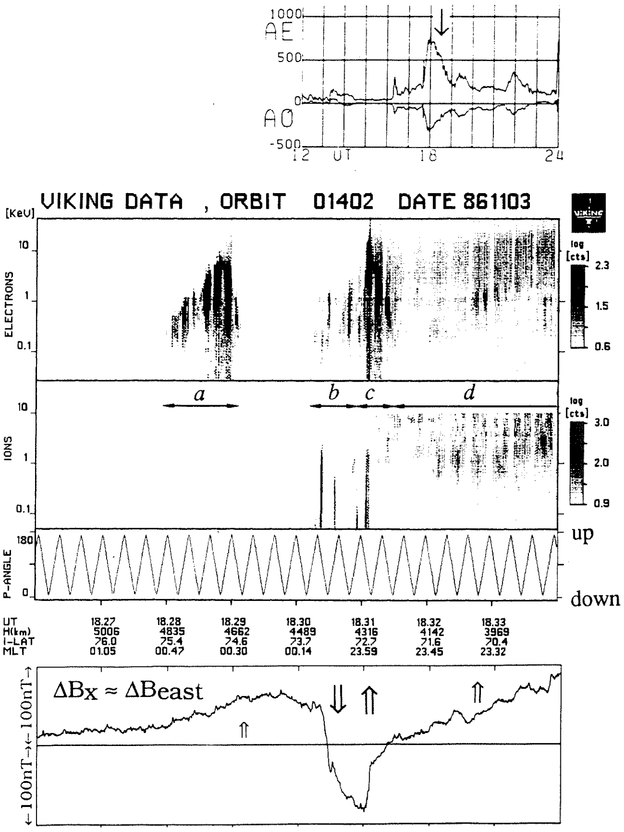

Fig. 2: Viking energy-time particle spectrogram and magnetic field data for the nightside traversal of orbit 1402, and the corresponding AE index. The empty arrow indicates directions and relative intensities of the field-aligned currents.

different between regions *b* and *c*. Region *b* is characterized by a strong downward FAC (1830:20-1831:00 UT) carried by downward ions while region *c*, the most active arc (1831:00-1831:30 UT), is characterized by a strong upward FAC carried by downward electrons. The last region *d* corresponds to the central plasma sheet (CPS) accompanied by an upward region 2 FAC.

This example clearly shows that the strong upward FAC on region *c* is different from the region 2 FAC on region *d*, indicating that the generation mechanisms of these FACs are different. It is more natural to consider the FACs in regions *b* and *c* as paired FACs. This agrees with our model of the substorm current wedge illustrated in Figure 1. The current intensity in region *c* is less than in region *b*, which also agrees with the present model. The existence of another arc on the poleward side of the paired FAC supports that the current wedge is on the closed field lines.

We have investigated all postmidnight traversals (0-3 MLT) of Viking during peaked AE (> 500 nT) conditions. Out of 15 examples of auroral arcs accompanied by intense field-aligned currents ($\Delta B > 100$ nT), 8 examples show clear double FAC structure within BPS, 5 examples show very weak double structure (very small spatial scale), and only two examples are not well explained. The last two examples are not consistent with the traditional current wedge either. Thus, the statistics are also supportive to our model.

4. CONCLUSION

We have shown that Viking observations of the double current structure in BPS during substorm expansive phases are consistent with our substorm current wedge model of the MHD fast wave illustrated in Figure 1. As the model predicts, the current wedge consists of a pair of FACs instead of single FAC of the traditional single current wedge. The additional part of the current wedge (equatorward part FAC) is linked with the longitudinal polarization current inside the MHD fast wave which works as a dynamo.

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