

## N O T I C E

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## Dynamics of Magnetosphere-Ionosphere Coupling including Turbulent Transport

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The dynamics of magnetosphere-ionosphere coupling has been investigated by means of a two-dimensional two fluid MHD model including anomalous resistivity. When field-aligned current is generated on auroral field lines, the disturbance propagates towards the ionosphere in the form of a kinetic Alfvén wave. When the current exceeds a critical value, microscopic turbulence is produced, which modifies the propagation of the Alfvén wave. This process is modelled by a non-linear collision frequency, which increases with the excess of the drift velocity over the critical value. Turbulence leads to absorption and reflection of the Alfvén wave, partially decoupling the generator from the ionosphere. The approach to a steady-state is strongly dependent on the presence or absence of the turbulence. The current is self-limiting, since a current in excess of critical causes a diffusion of the magnetic field perturbation and a reduction of current. The transverse scale size is determined by a balance between the non-linear steepening of the wave and the diffusion caused by the turbulence.

The coupling of magnetosphere and ionosphere by field-aligned currents is one of the most important problems of magnetospheric and auroral physics. Previous models of auroral electrodynamics generally either have ignored microscopic processes such as plasma turbulence, or have considered only the microscopic processes, without reference to the large-scale processes which feed energy to the turbulence. We have attempted to bridge this gap by means of a two-dimensional MHD model, which includes a term to represent a resistivity due to plasma turbulence.

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The computer model allows variations in the  $xz$  plane, where  $x$  represents the latitudinal direction and  $z$ , the direction of the background magnetic field, which is assumed to be constant in space and time. The field aligned current is, then, represented by a magnetic perturbation  $B_y$ . The electric field then has components in the  $xz$  plane. The equations describing induction, ion polarization drift, continuity, and electron motion along the field, in conjunction with Ampere's Law, then determine the evolution of the system. In the linear limit, these equations yield the dispersion relation for kinetic Alfvén waves in a cold plasma:

$$\omega = k_{\parallel} V_A (1 + k_{\perp}^2 c^2 / \omega_{pe}^2)^{-1/2}$$

In the model, terms which are less than the electron-ion mass ratio are neglected, which leaves the convective nonlinearity as the main nonlinear contribution. In this limit, electron motion is along the background field, whereas the ions move only across field lines.

Turbulence is modelled by means of an effective drag term introduced into the electron equation of motion. When the electron drift velocity  $u$  is greater than the critical value for instability, this drag term has the form:

$$f^* = \nu^*(u)(u - u_{crit})$$

$$\nu^*(u) = \nu_1 + \nu_2 \left[ \frac{u - u_{crit}}{u_{crit}} \right]^n$$

The drag term is of the opposite sign for  $u < -u_{crit}$  and is zero when  $|u| < u_{crit}$ . For electrostatic ion cyclotron turbulence saturated by resonance broadening, one finds  $n = 2$ ,  $\nu_1 \approx 0.2 \Omega_i$ ,  $\nu_2 \approx 0.04 \Omega_i$ , where  $\Omega_i$  is the ion gyrofrequency. In the model,  $\nu_1$  and  $\nu_2$  are taken to be independent of space and time, while  $u_{crit}$  is allowed to be a function of  $z$ .

On one end of the system, representing the ionosphere, a height integrated Pedersen conductivity is specified which causes Alfvén waves to be reflected. For realistic ionospheric values ( $\Sigma_p \sim 10$  mhos) the Alfvén wave is almost perfectly reflected. On the other end, a generating field is imposed. Both current and voltage generators can be considered by specifying  $B_y$  and  $E_x$ , respectively, as a function of  $x$  and of time at this end of the system.

In the absence of turbulent drag, the system evolves much as in the work of *Gixert and Boswell* [1979]. Since the ionospheric height integrated conductivity is generally much greater

than the Alfvén wave impedance  $\Sigma_A = c^2 / (4\pi V_A \sqrt{1 + k_{\perp}^2 / \omega_{pe}^2})$ , an Alfvén wave pulse incident on the ionosphere will be reflected with  $E_x$  reversed and  $B_y$  in the same direction. If  $E_x$  is fixed in the generator, the current will increase until a steady state is achieved in which  $E_x$  is independent of  $z$  and the ionospheric Pedersen current is given by the imposed  $E_x$  and the assumed Pedersen conductivity. Similarly, if  $B_y$  is imposed,  $E_x$  will decrease until Ohm's Law is satisfied in the ionosphere.

In the presence of turbulence, the situation is changed dramatically. When an Alfvén wave pulse encounters a region of turbulence, it is partially reflected, transmitted, and absorbed [Lysak and Carlson, 1981]. The wave pulse is reflected in the opposite sense as reflections from the ionosphere; that is, the  $B_y$  component is reversed. Thus regions above a turbulent region will have strong  $E_x$  and weak  $B_y$  components, while on quiescent field lines,  $E_x$  will be weak and  $B_y$  strong. In this case, if  $E_x$  is imposed, magnetic field lines will diffuse on field lines where turbulence is present, leading to a broader distribution of current than that originally imposed. On the other hand, when  $B_y$  (and thus, the current profile) is imposed,  $E_x$  is enhanced in regions where the current, and thus the turbulence, is strongest. This leads to the formation of narrow V-shaped potential structures on field lines where turbulence is present.

The effect of ionospheric and turbulent regions on the generator may be discussed by recalling that  $E_x$  may be interpreted as a plasma flow in the  $y$  direction. When a pulse is reflected by the ionosphere, the field-aligned current is increased, causing an increase in the  $j \times B$  force which resists the plasma flow. When the pulse reflects off the turbulent region, however, the generator is cut off from the ionosphere and the flow speed may increase due to a reduction in the  $j \times B$  force. This may provide a mechanism for plasma injection on field lines which contain turbulence.

The approach to a quasi-steady-state can occur much more rapidly in the presence of turbulence. V-shaped potential structures are formed within one or two bounce periods. Integral properties of the system, such as potential drop and total energy dissipation, may reach constant values while local properties are still oscillating. Thus, the presence of a steady arc structure

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does not necessarily imply that the flux tube is locally in a steady state.

### References

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