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ELECTRIC FIELD AND ENERGY TRANSFER BY MAGNETOPAUSE RECONNECTION

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Abstract. Expressions related to those commonly being used in the recent literature to describe the electric field and energy transfer from the solar wind to the earth's magnetosphere are presented in this work, in a unified form, from models of large scale-magnetopause reconnection. New explicit expressions related to the component of the reconnection current, parallel and transverse to the geomagnetic field at the magnetopause, are also given. Furthermore, a new expression for the electric power related to the components of the reconnection electric field and current, that could exist parallel to the geomagnetic field, is also presented. These new derived quantities are suggested to be used in future attempts to incorporate more features of magnetopause reconnection to the study of electric field and energy transfer at the earth's magnetopause. One example of such an attempt is suggested, in which the Svalgaard-Mansurov effect could be regarded as one consequence of the presence of a finite parallel component of the reconnection current, with its direction governed by that of the dawn-dusk component of the interplanetary magnetic field (B_y).

Introduction

Several studies on the electric coupling between the solar wind and the Earth's magnetosphere (Perreault and Akasofu, 1978; Akasofu, 1981; D'Angelo and Goertz, 1979; Kan and Lee, 1979; Gonzalez and Gonzalez, 1981, 1984; Reiff et all., 1981; Wygant et al., 1983; Bythrow and Potemra, 1983; Doyle and Burke, 1983; Stanislawska and Prölss, 1984; Tsurutani et al., 1984, among others) have shown that quantities related to the reconnection process at the Earth's magnetopause describe well this coupling, when compared to magnetospheric parameters that represent some of the effects of such a coupling. Among those quantities, an expression called ε (Perreault and Akasofu, 1978) has been successfully compared to dissipation parameters of the magnetosphere, mainly AE and U_T (Akasofu, 1981). However, more generalized quantities, that involve ε for simple cases, have been also shown to correlate even better with U_T (Gonzalez and Gonzalez, 1984; Stanislawska and Prölss, 1984).

It is the purpose of this work to show that most, if not all, of the expressions (quantities) used in the above mentioned literature can be derived simply from large scale reconnection models, such as that given by Gonzalez and Mozer (1974), and to propose further quantities which could be also compared to related effects in the magnetosphere. Among those effects, the Svalgaard-Mansurov effect could be intimately related to an electric current-transfer between the northern and the southern hemispheres involved in asymmetric reconnection, namely when $B_y \neq 0$ (Gonzalez and Mozer, 1974).

Electric Field Transfer

The expression for the total electric field due to magnetopause reconnection (Gonzalez and Mozer, 1974) is, in gaussian units:

$$E(S,\Theta) = (1/C)\ V\ B_T\ F(S,\Theta); \qquad (1a)$$

where V is the solar wind speed; B_T, the transverse component of the interplanetary magnetic field: $B_T \equiv (B_y^2 + B_z^2)^{1/2}$ in solar-magnetospheric coordinates, and $F(S,\Theta)$ is a function that describes the projection of the magnetosheath electric field to the reconnection line, given by Gonzalez and Mozer (1974) and by Gonzalez and Gonzalez (1981), as:

$$F(S,\Theta) = \sin(\Theta-\beta) = (1 - S\cos\Theta) / (1+S^2 - 2S\cos\Theta)^{1/2}, \qquad (2)$$

with $S \equiv |\underline{B}_G| / |\underline{B}_M| \geqq 1$, Θ the angle between the geomagnetic field $\underline{B}_G$ and the magnetosheath magnetic field $\underline{B}_M$ at the magnetopause and β the angle between the geomagnetic field $\underline{B}_G$ and the reconnection line LL' (Figure 1a). Note that $F(S,\Theta) = 0$ for $S\cos\Theta \geqq 1$.

Gonzalez and Mozer also presented a modified expression for $E(S,\Theta)$, when geometrical effects introduced by the shape of the dayside magnetopause on the curvature of the reconnection line were taken into account and represented by the correction function $\lambda(\Theta) \equiv (\sin\Theta/2)^{-1}$. Thus, with this modification:

$$E_\lambda(S,\Theta) = (1/C)\ V\ B_T\ F(S,\Theta)\ (\sin\Theta/2)^{-1}. \qquad (1b)$$

However, later Gonzalez and Gonzalez (1981) argued that this correction factor may be cancelled by a similar, but opposite, geometrical effect created on the curvature of the reconnection line by the presence of the clefts.

Gonzalez and Gonzalez (1981) argued that some magnetospheric parameters could be better related either to the transverse (Dawn-Dusk) or to the parallel components of the reconnection electric field with respect to $\underline{B}_G$. These components (shown on Figure 1a, where the Dawn-Dusk direction is the line DD') are:

$$E_D(S,\Theta) = (1/C)\ V\ B_T\ (1-S\cos\Theta)\ \times$$

$$\times\ (S - \cos\Theta)/(1+S^2 - 2S\cos\Theta). \tag{3}$$

$$E_{\shortparallel}(S,\Theta) = (1/C)\ V\ B_T\ \sin\Theta(1-S\cos\Theta)$$

$$/(1+S^2 - 2S\cos\Theta). \tag{4}$$

The above given expressions are general. For the limit that $S \to 1$, namely $|\underline{B}_G| = |\underline{B}_M|$ at the magnetopause, these expressions become:

$$E(1,\Theta) = (1/C)\ V\ B_T\ \sin(\Theta/2) \tag{5a}$$

$$E_\lambda(1,\Theta) = (1/C)\ V\ B_T, \tag{5b}$$

$$E_D(1,\Theta) = (1/C)\ V\ B_T\ \sin^2(\Theta/2), \tag{5c}$$

$$E_{\shortparallel}(1,\Theta) = (1/C)\ V\ B_T\ \sin(\Theta/2)\cos(\Theta/2). \tag{5d}$$

Expression (5b) can be identified with the generalized classical V B_z function. Expression (5c) is similar to that given by Kan and Lee (1979). Expressions (1a), (1b), (5a), (5b) and (5c) have been already compared successfully to related electric field measurements (Reiff et al., 1981; Sonnerup et al., 1981; Wygant et al., 1983; Doyle and Burke, 1983 and Gonzalez, 1984) and to electric current measurements (Bythrow and Potemra, 1983). Since expression (5c) had a great success when compared to measurements, one expects that its generalized version, namely expression (3), would give interesting results as well. Expressions (4) and (5d), that refer to the component of the reconnection electric field parallel to the geomagnetic field, have not been yet compared to related magnetospheric parameters, due to the difficult task of measuring parallel electric fields at the magnetopause (Mozer, private communication). As illustrated in Figure 1a, this parallel electric field (with a typical value of 0.5 m V/m) could be a source of particle acceleration at the magnetopause in the case that it does not get screened out by electrons and, especially, if the conductivity along the geomagnetic field is lowered at the local magnetopause by the presence of turbulence (Tsurutani et al., 1981).

Electric Power

Expressions for the electric power, related to the total and component electric fields given above, can be obtained when those electric fields are multiplied by the appropriate expressions for the currents and by the length of the reconnection line. This length was approximated by 2R (Gonzales and Mozer, 1974), with R being the radius of the dayside magnetopause at the nose. The total reconnection current was given by Gonzalez and Mozer (1974) as:

$$I = (C/2\pi)\ R\ |\underline{B}_G - \underline{B}_M| \tag{6a}$$

In order to get the transverse and parallel components of this current with respect to the geomagnetic field at the magnetopause, one has to multiply the expression (6a), for the total current, by the transverse and parallel-projection functions $G(S,\Theta)$ and $H(S,\Theta)$, respectively, given by Gonzalez and Gonzalez (1981), namely:

$$I_D = I\ G(S,\Theta) = (C/2\pi)\ R\ |\underline{B}_G - \underline{B}_M|\ x$$

$$x\ (S - \cos\Theta)/(1 + S - 2S^2 \cos\Theta)^{1/2} \tag{6b}$$

$$I_{\parallel} = I\ H(S,\Theta) = (C/2\pi)\ R\ |\underline{B}_G - \underline{B}_M|\ x$$

$$x\ \sin\Theta/(1 + S^2 - 2S^2 \cos\Theta)^{1/2} \tag{6c}$$

The corresponding current densities are shown in Figure 1b.

Thus, the corresponding expressions for the electric power are:

$$P_W(S,\Theta) = (1/\pi)\ V\ R^2\ B_T\ B_M\ W(S,\Theta), \tag{7}$$

with $W(S,\Theta) = (1 - S\cos\Theta)$, for the total power,

$$P_K(S,\Theta) = (1/\pi)\ V\ R^2\ B_T\ B_M\ K(S,\Theta), \tag{8}$$

with $K(S,\Theta) = (1 - S\cos\Theta)(S - \cos\Theta)^2/(1 + S^2 - 2S\cos\Theta)$, for the power related to the transverse components E_D and I_D, and

$$P_{\parallel}(S,\Theta) = (1/\pi)\ V\ R^2\ B_T\ B_M\ Y(S,\Theta), \tag{9}$$

with $Y(S,\Theta) = \sin^2\Theta\ (1 - S\cos\Theta)/(1 + S^2 - 2S\cos\Theta)$, for the power related to the parallel components $E_{\parallel}$ and $I_{\parallel}$.

Expressions (7) and (8) have been already discussed before by Gonzalez and Gonzales (1981, 1984).

For the limit $S \to 1$, and using $B_T B_M \sim (\pi/2)B^2$, where B is the amplitude of the interplanetary magnetic field, expressions (7), (8) and (9) become:

$$P_W(1,\Theta) \approx V\ R^2\ B^2\ \sin^2(\Theta/2), \tag{10a}$$

$$P_K(1,\Theta) \approx V\ R^2\ B^2\ \sin^4(\Theta/2), \tag{10b}$$

$$P_{\parallel}(1,\Theta) \approx V\ R^2\ B^2\ \sin^2(\Theta/2)\ \cos^2(\Theta/2). \tag{10c}$$

Expressions (10a) and (10b) have been widely studied in the literature, mainly expression (10b), which is identified with the quantity $\varepsilon \equiv V \ell_0^2 B^2 \sin^4 (\Theta/2)$, given by Perreault and Akasofu (1978), when $R \equiv \ell_0$. The quantity ε was successfully compared to dissipation parameters of the magnetosphere, mainly U_T (Akasofu, 1981; Tsurutani et al., 1984, among others). However, expression (8), which is more general than ε,and expression (7) have been recently shown to correlate with U_T with better correlation coefficients than those obtained between ε and U_T (Gonzalez and Gonzalez, 1984; Stanislawska and Prölss, 1984). On the other hand, expressions (9) and (10c) are new and still have to be compared to related dissipation parameters of the magnetosphere. For instance, part of the energy related to dayside auroras could have an origin in processes related to these expressions, that involve electric fields and currents parallel to $\underline{B}_G$ at the magnetopause.

Conclusions

The general and simplified expressions given above reduce to most, if not to all, the quantities studied in the literature with respect to the electric field and power transfer at the magnetopause. Thus, one can conclude that magnetopause reconnection is an important process responsible for the coupling between the solar wind and the magnetosphere and that large scale reconnection models, like that given by Gonzalez and Mozer (1974), represent well basic features of the reconnection process.

Besides the expressions (9) and (10c), the expression (6c) for the component of the reconnection current parallel to $\underline{B}_G$ is also given for the first time. This current is directed from the southern to the northern hemisphere when $B_y > 0$, as illustrated in Figure 1b. It has the opposite direction when $B_y < 0$. Thus, one could expect that this current would involve a net current transfer from one hemisphere to the other, probably extending its effect down to the local ionospheres. In this way, this current redistribution could be related to the well known ΔZ changes that occur at high latitudes in response to $\pm B_y$ and in association to the Svalgaard-Mansurov effect. The expected amplitudes of such effect may be related to changes in zonal ionospheric currents governed by $I_{\parallel}$. From expression (6c), the typical value for $I_{\parallel}$ is $\sim 5\times10^5$ amperes.

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Figure Captions

Figure 1(a) View from the sun of the dayside magnetopause, in which the reconnection electric field $\underline{E}_R$ and its components E_D and $E_{\parallel}$, transverse and parallel to the geomagnetic field $\underline{B}_G$, are illustrated for a case with $B_y > 0$. The line LL' is the reconnection line. The line DD' is the Dawn-Dusk line. $\underline{B}_M$ is the magnetosheath magnetic field at the magnetopause. The angles Θ and β are explained in the text. (b) Same view as in (a), where the reconnection current $\underline{J}_R$ and its components J_D and $J_{\parallel}$, transverse and parallel to the geomagnetic field $\underline{B}_G$, are illustrated for a case with $B_y > 0$.

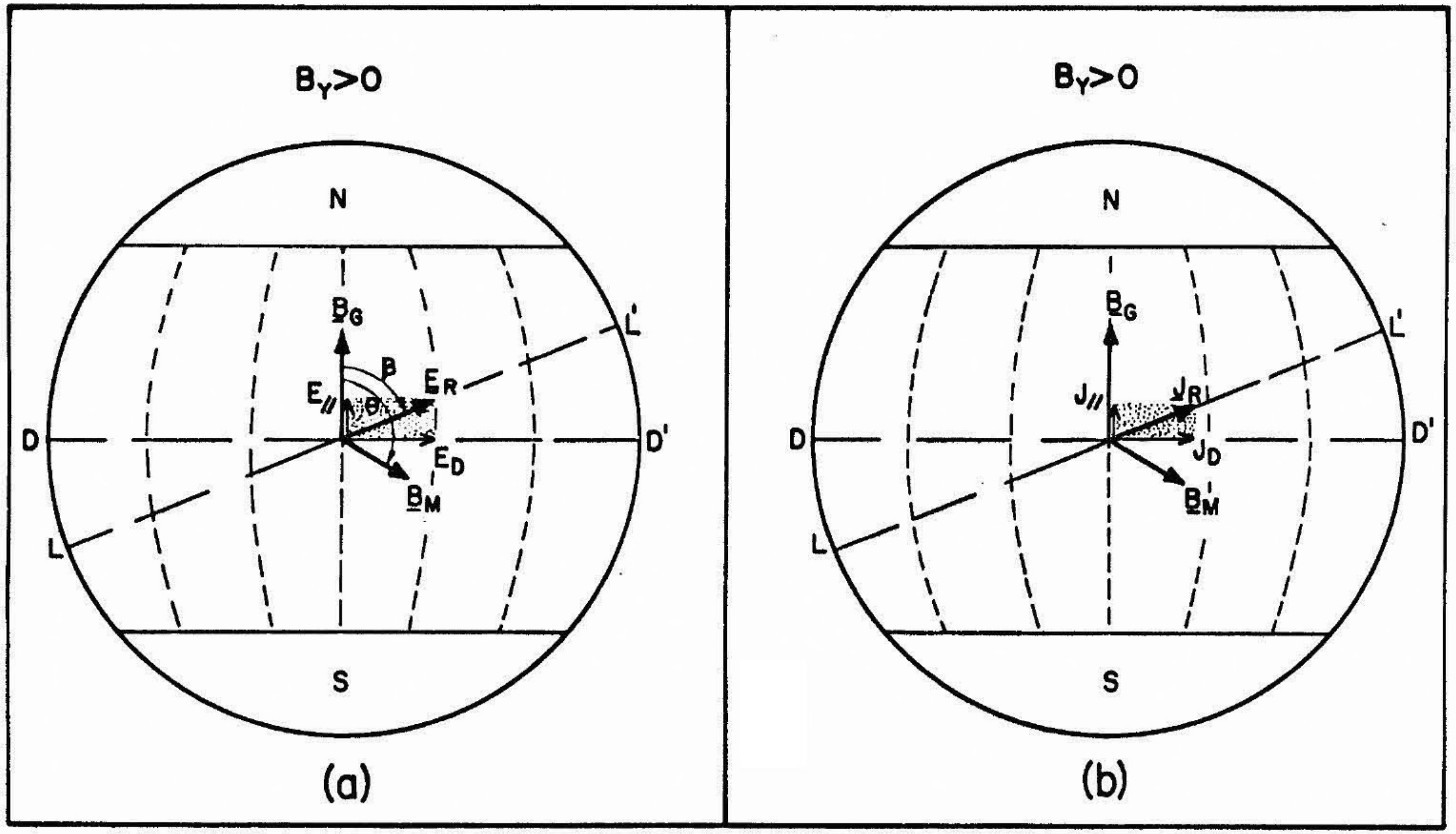

Fig. 1