1. Classification *INPE-COM.4/RPE* *CDU: 523.4-854*	2. Period	4. Distribution Criterion internal [ ] external [X]
3. Key Words (selected by the author) *MAGNETOPAUSE RECONNECTION* *ELECTRIC FIELDS* *ENERGY TRANSFER*		
5. Report Nº *INPE-1940-RPE/259*	6. Date *November, 1980*	7. Revised by *E.C.* *A. E. Costa Pereira*
8. Title and Sub-title *SOLAR WIND ENERGY AND ELECTRIC FIELD TRANSFER TO THE EARTH'S MAGNETOSPHERE VIA MAGNETOPAUSE RECONNECTION*		9. Authorized by *Parada* *Nelson de Jesus Parada* *Director*
10. Sector *DAS/DIG* Code *30.293*		11. Nº of Copies *08*
12. Authorship *W. D. Gonzalez A.* *A.L.C. de Gonzalez*		14. Nº of Pages – *16*
13. Signature of the responsible *W. Gonzalez A.*		15. Price

16. Summary/Notes

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17. Remarks *This work was partially supported by the "Fundo Nacional de Desenvolvimento Científico e Tecnológico - FNDCT" under contract FINEP-537/CT. This work was submitted for publication in the GRL.*

SOLAR WIND ENERGY AND ELECTRIC FIELD TRANSFER TO THE EARTH'S MAGNETOSPHERE VIA MAGNETOPAUSE RECONNECTION

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ABSTRACT

Some general expressions for the convection and parallel electric fields as well as for the energy transfer, due to magnetopause reconnection, are derived using a nose-reconnection model that takes into account the presence of the clefts. For the case of equal geomagnetic and magnetosheath field amplitudes, the expression for the power dissipated by the convection electric field reduces to the substorm parameter ε widely discussed in the recent literature. This result suggests that magnetopause reconnection is defined at the nose with a tilted reconnection line, but that the convection electric field is related only to the dawn-dusk component of the reconnection electric field, as defined at high latitudes (clefts).

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INTRODUCTION

Recent work on the interplanetary energy transfer to the earth's open magnetosphere (Perreault and Akasofu, 1978; Akasofu, 1979a, 1979b; D'Angelo and Goertz, 1979; Kan and Lee, 1979) has motivated the present derivation of some general expressions for the energy transfer and the electric field related to magnetopause reconnection. For the particular case of equal magnetosheath and geomagnetic reconnecting fields at the magnetopause, the expression for the power effectively transferred to the magnetosphere reduces to the substorm parameter ε (also called interplanetary quantity) discussed in the above cited literature.

The present work is based on the magnetopause reconnection model of Gonzalez and Mozer (1974), in which several simplifying assumptions were used. Among them, it was considered that reconnection occurs on the whole dayside magnetopause of cross section 2R, with R being the magnetopause radius at the nose, and without terminators at high latitudes. However, if one takes into account the presence of the clefts, the effective area for reconnection is expected to reduce, and the expression for the potential of reconnection becomes less sensitive to the geometric factor (λ) introduced by Gonzalez and Mozer (1974) to allow for a curvature-effect presented by a real magnetopause, mainly at high latitudes. Thus, the expression for the potential at the reconnection line (Gonzalez, 1973) to be used below is (in gaussian units):

$$\Phi = (2/c)\, V\, R\, B_T\, F(B_G/B_M, \theta) \qquad (1)$$

where V is the solar wind speed, B_T the transverse component of the interplanetary magnetic field (IMF), $B_T \equiv (B^2{}_y + B^2{}_z)^{1/2}$, and $F(B_G/B_M, \theta)$ the angular function defined in the appendix. The function F represents the effective projection of the interplanetary electric field (VB_T/c) on the reconnection line of length 2R. The magnetosheath field, B_M, was assumed by Gonzalez an Mozer (1974) to be related to the B_T field as $B_M = q\, B_T$, with q being a compressional parameter, which in average takes a value of 5.

In Figure 1, the interplanetary electric field along the line $\overline{EE}$, when projected on the reconnection line $\overline{LL}$, gives the reconnection electric field $E_L = (V/c)\, B_T F(s, \theta)$, with $s \equiv B_G/B_M$.

Gonzalez (1973) computed the energy dissipated at the magnetopause per unit time due to reconnection as $P = \Phi \,.\, I$, with I being the total magnetopause current due to reconnection and given by $I = (c/2\pi)\, R\, |\underline{B}_G - \underline{B}_M|$. It was claimed that this power was dissipated only at the magnetopause. However, in the present work the meaning of P is more general, as discussed below.

ELECTRIC FIELDS

The total electric field E_L due to the reconnection process might be considered as being composed by a dawn-dusk component, transmitted at high latitudes (clefts) as a convection field, and by a meridional component parallel to the geomagnetic field.

Thus, the convection electric field E_D would be given by a projection of the total field E_L, along the line $\overline{DD}$ of Figure 1, namely:

$$E_D = E_L\, G(s, \theta) = (V/c) B_T F(s, \theta) G(s, \theta) = (V/c) B_T M(s, \theta) \qquad (2)$$

where the functions $G(s, \theta)$ and $M(s, \theta)$ are defined in the appendix. The function $M(s, \theta)$ is plotted in Figure 2 for some values of the parameter s.

Similarly, the parallel electric field would be given by:

$$E_{\parallel} = E_L H(s, \theta) = (V/c)B_T F(s, \theta)H(s, \theta) = (V/c)B_T N(s, \theta) \qquad (3)$$

where the functions $H(s, \theta)$ and $N(s, \theta)$ are defined in the appendix. The function $N(s, \theta)$ is plotted in Figure 3 for some typical values of the parameter s.

The above expressions hold for $s > 1$ and $\cos\theta < 1/s$, namely $B_M > B_G \cos\theta$ (Gonzalez and Mozer, 1974). When $\cos\theta \geq 1/s$, $E_D = E_{\parallel} = 0$. When the geomagnetic and magnetosheath fields are assumed to have equal amplitudes at the magnetopause, namely $B_G = B_M$ and $s = 1$, the convection and parallel electric fields reduce from equations 2 and 3, respectively, to $E_D = (V/c)\, B_T \sin^2(\theta/2)$ and $E_{\parallel} = (V/c)\, B_T \sin(\theta/2) \cos(\theta/2)$.

For typical values of the interplanetary parameters, namely $V \approx 400$ km/sec and $B_T \approx 4$ gammas, and considering (from the appendix) that $M(s, \theta) \leq 1$ and $N(s, \theta) \leq 0.5$, one estimates for the convection electric field, $E_D \leq 2$ m V/m, and for the parallel field, $E_{\parallel} \leq 1$ m V/m.

ENERGY TRANSFER

If we are interested in the energy transferred from the solar wind to the magnetophere via magnetopause reconnection, and dissipated with the convection electric field, E_D, throughout the whole magnetospheric domain of the convection process, we could define an equivalent total magnetospheric current in the dawn-dusk direction established in the whole open magnetosphere. This total current, I_D, has to be fed by the reconnection process and, therefore, has to be related do the total change of the magnetosheath and geomagnetic fields in the dawn-dusk direction. Using Maxwell's equation, $\nabla \times \underline{B} = 4\pi\, \underline{J}/c$, and a scale length 2R in the dawn-dusk direction, one can estimate for this current (Gonzalez, 1973), $I_D = (c/2\pi)\ R\ |\underline{B}_G - \underline{B}_M|\ G(s,\theta)$. Thus, the power available for dissipation with the convection process is:

$$P_D = \Phi_D\ I_D = (1/\pi)\ VR^2\ B_T\ F(s,\theta)\ G^2(s,\theta)\ |\underline{B}_G - \underline{B}_M| =$$

$$= (1/\pi)\ VR^2\ B_T B_M K(s,\theta) \tag{4}$$

where the functions $F(s,\theta)$, $G(s,\theta)$ and $K(s,\theta)$ are defined in the appendix. The function $K(s,\theta)$ is plotted in Figure 4 for some typical values of s.

Equation 4 holds for $\cos\theta < 1/s$ and $s > 1$. When $\cos\theta \geqslant 1/s$, $P_D = 0$. When the geomagnetic and magnetosheath fields are assumed to have equal amplitudes at the magnetopause ($s = 1$), equation 4 reduces to $P_D = (2/\pi)\ VR^2 B_T B_M \sin^4(\theta/2)$. Assuming that $B_M = q\,B_T$, with q being the magnetosheath compressional parameters defined by Gonzalez and Mozer (1974), one gets $P_D = (2/\pi)\ VR^2 q\,B_T^2\ \sin^4(\theta/2)$. This expression for P_D can be compared with the substorm parameter (Akasofu, 1979a) $\varepsilon = VR^2B^2\sin^4(\theta/2)$, with B being the amplitude of the total IMF; since typically $B^2 \approx (2/\pi)\ q\,B_T^2$ for the most common values of q, namely $q = 3$, $q = 4$ and $q = 5$. Thus,

$$P_D\,(s = 1) = \varepsilon \approx VR^2B^2\sin^4(\theta/2) \tag{4a}$$

Considering that the magnetopause position is basically defined by pressure balance, and using a simple dipolar model for the geomagnetic field at the low latitude magnetopause, one could write equation 4 only in terms of solar wind parameters, as:

$$P_D = (B_o^2\ r_o^6 / 2\pi^4 m_+)^{1/3} (V/N_+)^{1/3}\, q\,B_T^2\ K(s,\theta)$$

with $s \equiv B_G/B_M = V(8\pi\, m_+ N_+)^{1/2} / q\,B_T$. Where r_o is the radius of the earth, B_o the surface geomagnetic field value, m_+ the proton mass and N_+ the solar wind density. Assuming, as above, $B^2 \approx (2/\pi)\, q\,B_T^2$:

$$P_D(\text{ergs/sec}) \approx 3 \times 10^{14}(V/N_+)^{1/3}\, B^2K(s,\theta) \tag{4b}$$

with V given in cm/sec, B in gammas and N_+ in cm^{-3}. The function $K(s,\theta)$ is given in the appendix for some values of s. Using typical values for the interplanetary parameters, $V = 4 \times 10^7$ cm/sec, B = 6 gammas $N_+ = 5$, and considering that $k(s,\theta) \leqslant 6$, one gets: $P_D \leqslant 10^{19}$ ergs/sec.

These equations could also be applied, with some restrictions, to the magnetospheres of Mercury, Jupiter, Saturn and of some stellar binary systems (Vasyliunas, 1979) in order to estimate their corresponding solar (or stellar) wind electric field and energy transfer. The plots shown in Figures 2, 3 and 4 do help with these estimates.

DISCUSSION

Expression 4a for the power dissipated by the convection electric field reduces better to the substorm parameter $\varepsilon = VB^2\, \ell_0^2 \sin^4(\theta/2)$, given by Akasofu (1979a), when R (defined at the nose) is measured at the clefts, as ℓ_0, with an expected smaller value. The validity of this expression has been checked with observations (Perreault and Akasofu, 1978; Akasofu, 1979a, 1979b) and claimed to follow closely the AE index. Similar comparisons of the AE index with the more general expression 4 for the energy transfer, as well as observational support for the convection and parallel electric fields (given by equations 2 and 3) are under present preparation.

The results obtained above suggest that the tilted magnetopause reconnection line and the interplanetary electric field transfer to the magnetopause are defined at the nose. However, the effective power delivered by the solar wind to the magnetosphere seems to be basically transmitted by the dawn-dusk component of the reconnection electric field (convection field) at high latitudes (clefts). Thus, the current I_D, used in our derivation for this power, represents the total magnetospheric current in the dawn-dusk direction fed by the reconnection generator. The meridional component of the electric field at the nose represents an electric field parallel to the geomagnetic field, which could also be dissipated with the field aligned current system involved in the magnetopause reconnection configuration. However, one expects that the power dissipated by the parallel electric field would basically energize particles at the dayside magnetopause and at its ionospheric extension (dayside auroras), without much contribution to the magnetospheric-tail energy input.

It would be interesting to include in the above given expressions the effects that the B_X component of the IMF (Gonzalez and Gonzalez, 1980) and the tilt-angle of the geomagnetic field (Murayama et al., 1980) are claimed to play in magnetopause reconnection. Preliminary studies suggest that this could partially be accomplished if the above expressions are multiplied by $(\bar{B}_X / B_X)$, with $\bar{B}_X$ being a normalizing average value of B_X. It was found that large values of B_X tend to reduce the efficiency of reconnection at the nose, and vice versa (Gonzalez and Gonzalez, 1980). Similarly, cases with large tilt angles could be reduced to those with large B_X values, and vice versa.

Finally, at the moment it is not yet possible to get definite estimates for the parameter q, since it is expected to be a complicated function of the pressure balance at the magnetopause, Bow shock properties, magnetosheath depletion, efficiency of the reconnection process, and so on.

ACKNOWLWDGMENTS

This work was partially supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico of Brazil.

APPENDIX

From Figure 1, the interplanetary electric field, along the line $\overline{EE}$, has a projection on the reconnection line $\overline{LL}$ through $\cos\left[90^{0} - (\theta - \beta)\right] = \sin(\theta - \beta)$, with:

$$F(s, \theta) \equiv \sin(\theta - \beta) = (B_M - B_G \cos\theta) / |\underline{B}_G - \underline{B}_M| =$$

$$= (1 - s\cos\theta) / (1 + s^2 - 2s\cos\theta)^{1/2}$$

where $s \equiv B_G / B_M$. This expression has a physical meaning only for $1 > s\cos\theta$ and $s > 1$, namely $B_M > B_G \cos\theta$ (Gonzalez and Mozer, 1974). Otherwise, $F(s, \theta) = 0$. When $s = 1$, $F(s, \theta) = \sin(\theta/2)$.

Similarly, any parameter defined at the reconnection line $\overline{LL}$ has a component on the dawn-dusk line $\overline{DD}$, through $\cos(90^{0} - \beta) = \sin\beta$, with:

$$G(s, \theta) \equiv \sin\beta = (B_G - B_M \cos\theta) / |\underline{B}_G - \underline{B}_M| =$$

$$= (s - \cos\theta) / (1 + s^2 - 2s\cos\theta)^{1/2}$$

This expression is always valid, since $s(\equiv B_G/B_M) \geqslant 1$ is always guaranteed at the magnetopause by pressure balance at an equillibrium situation of zero order. When $s = 1$, $G(s, \theta) = \sin(\theta/2)$.

Also, any parameter defined at $\overline{LL}$ has a meridional component, through $\cos\beta$, with:

$$H(s, \theta) \equiv \cos\beta = \left[1 - G^2(s, \theta)\right]^{1/2} = B_M \sin\theta / |\underline{B}_G - \underline{B}_M| =$$

$$= \sin\theta / (1 + s^2 - 2s\cos\theta)^{1/2}$$

Furthermore, we define:

$$M(s,\theta) \equiv F(s,\theta)\, G(s,\theta) = (1 - s\cos\theta)\,(s - \cos\theta) \,/\, (1 + s^2 - 2s\cos\theta)$$

$$N(s,\theta) \equiv F(s,\theta)\, H(s,\theta) = \sin\theta\,(1 - s\cos\theta) \,/\, (1 + s^2 - 2s\cos\theta)$$

$$Q(s,\theta) \equiv F(s,\theta)\, G^2(s,\theta)\, |\underline{B}_G - \underline{B}_M| = B_M K(s,\theta) =$$

$$= B_M(1 - s\cos\theta)\,(s - \cos\theta)^2 \,/\, (1 + s^2 - 2s\cos\theta)^{1/2}$$

These functions are so defined for $\cos\theta < 1/s$ and $s > 1$. When $\cos\theta \geqslant 1/s$, they are zero; and when $s = 1$, $M(s,\theta) = \sin^2(\theta/2)$, $N(s,\theta) = \sin(\theta/2)\cos(\theta/2)$ and $K(s,\theta) = 2\sin^4(\theta/2)$.

Figures 2, 3 and 4 show the plots of functions $M(s,\theta)$, $N(s,\theta)$ and $K(s,\theta)$ for some values of s.

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FIGURE CAPTIONS

Fig. 1 - View from the sun of the dayside magnetopause with the geomagnetic ($\underline{B}_G$) and magnetosheath ($\underline{B}_M$) field vectors at the nose, the reconnection line $\overline{LL}$, the interplanetary electric field line $\overline{EE}$ and the dawn-dusk line $\overline{DD}$.

Fig. 2 - The function $M(s, \theta)$ for some values of the parameter $s \equiv B_G/B_M$.

Fig. 3 - The function $N(s, \theta)$ for some values of the parameter $s \equiv B_G/B_M$.

Fig. 4 - The function $K(s, \theta)$ for some values of the parameter $s \equiv B_G/B_M$.

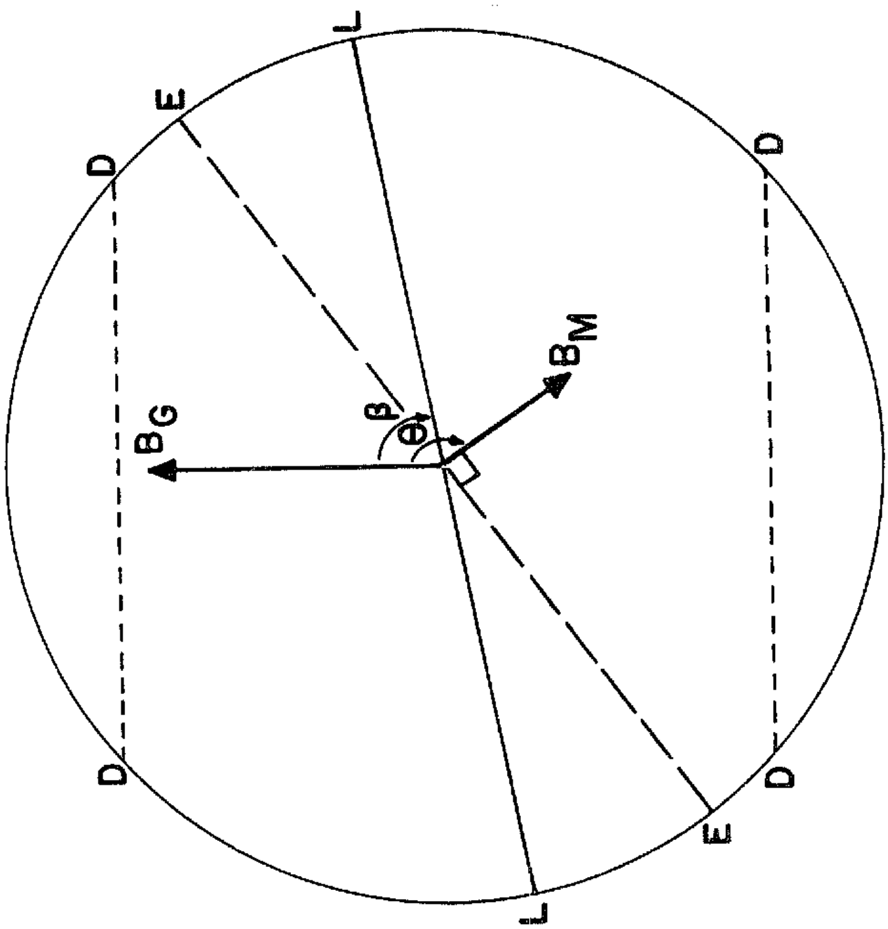

Fig. 1

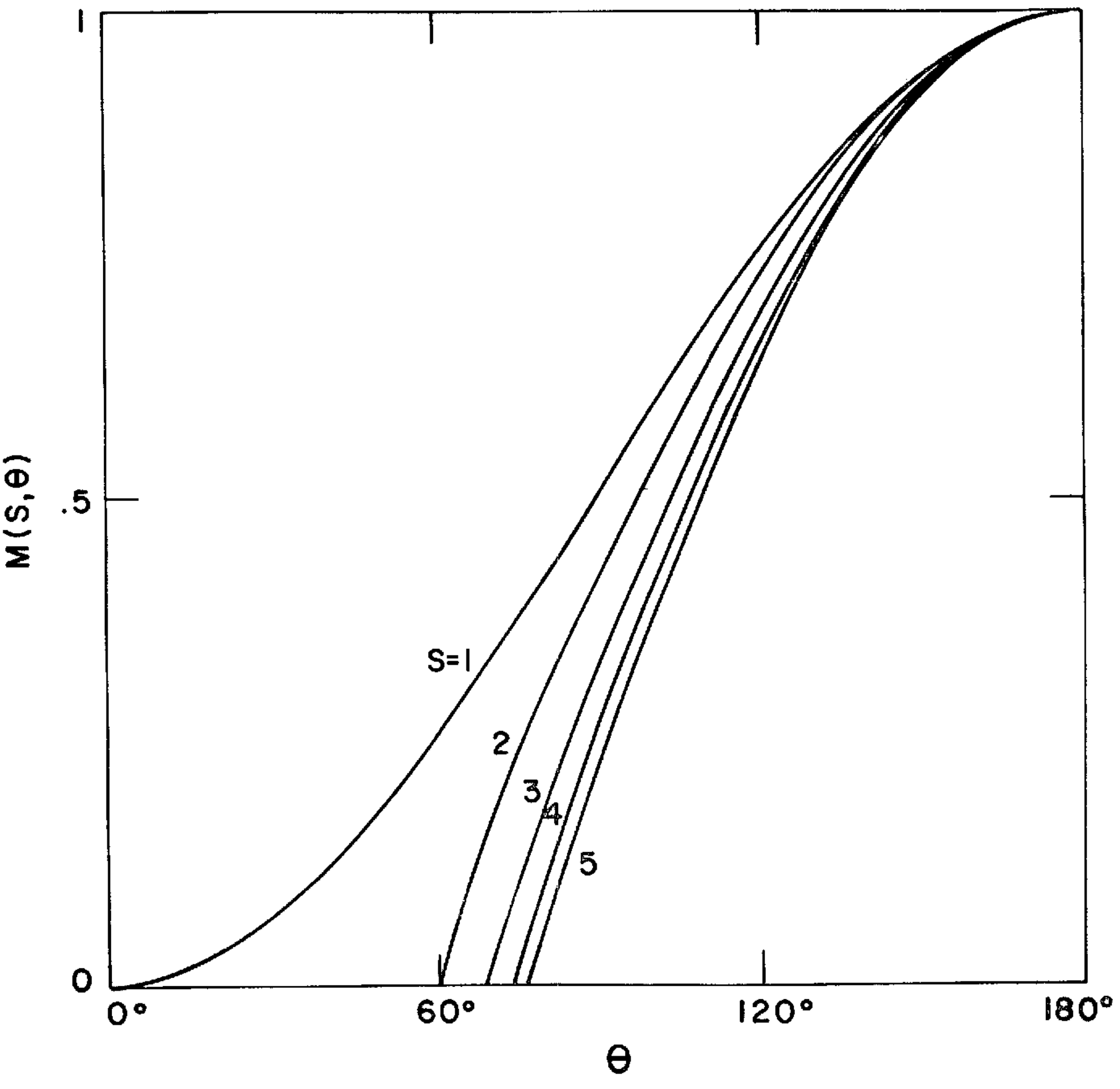

Fig. 2

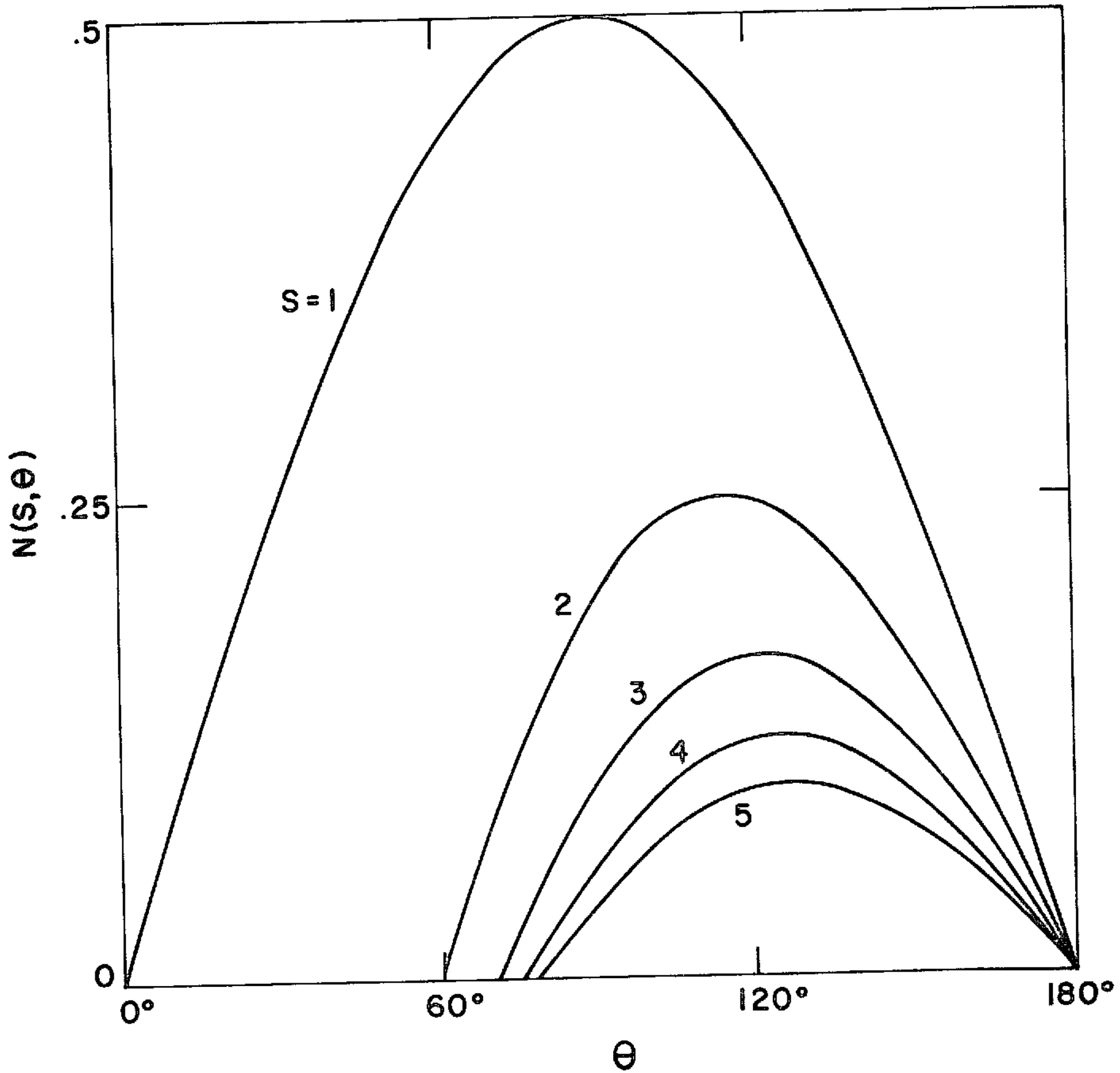

Fig. 3

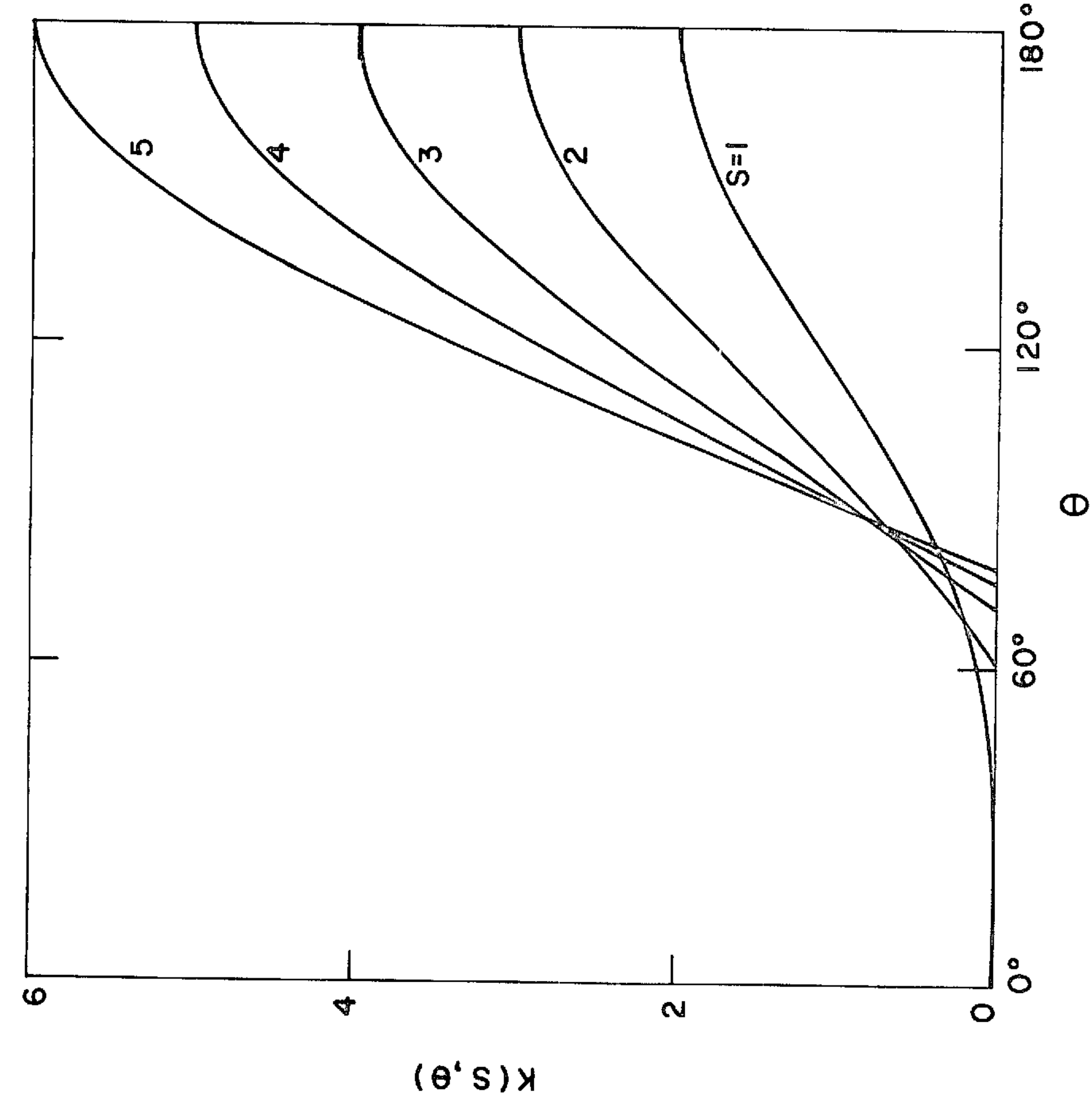

Fig. 4

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São José dos Campos, September 10, 1981

Ref.: 30.100.000.1424-81

Dr. F.T. Berkey
Center for Atmospheric and
Space Sciences
Utah State University
UMC 34
Logan, Utah 84322
U.S.A.

Dear Dr. Berkey:

Please find enclosed the abstracts of the following papers: "Solar Wind Electric Field Transfer to the Earth's Magnetosphere Via Magnetopause Reconnection" and "Large Scale Electric Field Measurements at Balloon Heights of the Brazilian Magnetic Anomaly", by W.D. Gonzales et alii, that we would like to submit for presentation in the 1982 Yosemite Conference - Origins of Plasmas and Electric Fields in the Magnetosphere, to be held in Yosemite, Ca., January 25-29, 1982.

Sincerely yours,

original assinado por
NELSON DE JESUS PARADA

Nelson de Jesus Parada
Director General

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2113

SOLAR WIND ELECTRIC FIELD TRANSFER TO THE EARTH'S MAGNETOSPHERE VIA MAGNETOPAUSE RECONNECTION

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and

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Berkeley - California 94720, U.S.A.

ABSTRACT

A revised model for the solar wind electric field transfer at the magnetopause due to reconnection will be presented. The dawn-dusk component of the computed electric field will be compared to tangential electric field measurements carried out by the ISEE Satellite at the magnetopause during events of enhanced reconnection. A discussion of an associated power transfer to the magnetosphere will be also given.

LARGE SCALE ELECTRIC FIELD MEASUREMENTS AT BALLOON HEIGHTS OF THE BRAZILIAN MAGNETIC ANOMALY

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and

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ABSTRACT

Large scale Electric Fields, measured for the first time at the Brazilian Magnetic Anomaly with balloon borne-double probe detectors, will be presented. A discussion of related low latitude ionospheric electric fields and their downward mapping (studied with computer simulations) will be also given.

INPE 1940 DA9 DGA

São José dos Campos, August 31, 1983

Ref.. 30.100.000.1298-83

Dr. E.W. Hones, Jr.
Los Alamos National Laboratory
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Los Alamos, New Mexico 87545
U.S.A.

Dear Dr. Hones:

Please find enclosed the Abstract of the paper "Solar Wind-Energy and Electric Field-Transfer to the Earth's Magnetosphere via Magnetopause Reconnection", by W.D. Gonzalez, which we would like to submit for presentation at the "Chapaman Conference on Magnetic Reconnection" to be held at Los Alamos during the time interval of October 3-7, 1983.

Since, due to Governamental restrictions for traveling to attend Conferences, we shall not be able to finance Dr. Gonzalez's trip to Los Alamos, I understand that he will try to cover the travel expenses by his own.

Sincerely yours,

original assinado por
NELSON DE JESUS PARADA
Nelson de Jesus Parada
Director General

Mail correspondence to:

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12200 - São José dos Campos - SP
Brazil

WDGA/zl

SOLAR WIND-ENERGY AND ELECTRIC FIELD-TRANSFER TO THE EARTH'S MAGNETOSPHERE VIA MAGNETOPAUSE RECONNECTION

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EXTENDED ABSTRACT

From a comparison of values of the magnetopause-electric field computed from the reconnection model of Gonzalez and Mozer (1974) with those measured by the ISEE-1 satellite during eleven consecutive crossings of the magnetopause, for which the interplanetary magnetic field showed a steady southward component, the following results were obtained about the efficiency of transmission of the interplanetary electric field to the Earth's magnetosphere. The interplanetary electric field diminished its amplitude by about 50% between the bow shock and the magnetopause due to the non-rectilinear flow in the magnetosheath. Then, a fraction of about 70% was transmitted to the magnetosphere at the reconnection line. Thus, about 40% of the interplanetary-electric field's amplitude seems to have been transmitted to the magnetopause during those ISEE-1 crossings. Furthermore, the average direction of the measured electric field was very close to that predicted by the model.

An expression for the magnetopause-reconnection power (P_K), based on the dawn-dusk component of the reconnection electric field (Gonzalez and Gonzalez, 1981), that reduces to the substorm parameter ε (Perreault and Akasofu, 1978) for the limit that involves equal geomagnetic (B_G) and magnetosheath (B_M) magnetic field amplitudes at the magnetopause, is contrasted with the expression for the power (P_W) based on the whole reconnection electric field vector (Gonzalez and Mozer, 1974). Correlation studies show that P_K seems to correlate with the empirical dissipation parameter U_T (Akasofu, 1981) with slightly better correlation coefficients than those obtained between the parameter ε and U_T as well as between the expression P_W and U_T. These better correlation coefficients show up for the more familiar values of the ratio $B_G/B_M > 1$ and seem to maximize, at least for the cases studies, around the average value $\langle B_G/B_M \rangle \approx 1.6$.

Therefore, although measurements of the magnetopause-electric field do support the values predicted by the reconnection model of Gonzalez and Mozer (1974), the correlation studies seem to indicate that the power input to the magnetosphere is mainly related to the dawn-dusk component of the reconnection electric field. This indication is argued to be related to the effective transmission of the reconnection electric field by the geomagnetic field, which itself extends mainly transverse to the dawn-dusk direction at the front-side magnetopause, and to the net set-up of the combined Chapman-Ferraro and reconnection currents. In this way, one expects that the parallel component of the reconnection electric field (parallel to the geomagnetic field) affects only the medium at the front-side magnetopause, not being

transmitted downstream. On the other hand, the transmitted dawn-dusk component is argued to lead to magnetospheric convection and to related dissipative processes within the whole magnetosphere.

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