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16. Summary/Notes

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17. Remarks

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INFLUENCE OF THE B_x COMPONENT OF THE INTERPLANETARY MAGNETIC FIELD ON MAGENTOPAUSE RECONNECTION

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ABSTRACT

A first clear evidence of an effect of the B_x component (in Solar Magnetospheric Coordinates) of the Interplanetary Magentic Field (IMF) on magnetopause reconnection has been obtained from polar ionospheric electric fields measured with balloons during an away sector of the IMF. This B_x - effect is such that larger electric field values were measured when B_x was small, and vice versa, during intervals of time with $B_z \leq 0$, and while the transverse component of the IMF ($B_t \equiv \sqrt{B_y^2 + B_z^2}$) and the solar wind speed had approximately constant values. For those cases, changes of B_x from 2 to 8 gammas are found to account for as much as a factor of two decrease in the magnitude of the convection electric field at the polar cap. When $B_z > 0$, there is also some indication that the measured dusk to dawn polar cap electric field (reversed convection) became larger when $|B_x|$ was small and vice versa.

During the last decade, magnetopause reconnection has been successfully advocated as a mechanism to explain most of the basic features of mass, momentum and energy transfer from the solar wind to the magnetosphere of the Earth. Although the exact nature of this process is not fully yet understood, some gross models have been developed to follow the basic changes in the topology of the reconnected geomagnetic and interplanetary field lines and to compute the resultant effective potential across the magnetosphere (Nishida 1978).

In particular, in the model by Gonzalez and Mozer (1974); it was assumed that magnetopause reconnection operates between non polar geomagnetic field lines and interplanetary field lines that approach the magnetopause boundary in a plane perpendicular to the Earth-Sun axis, thus neglecting the component of the IMF along that axis (x-direction in Solar Magnetospheric Coordinates). When the electric field computed from that model was compared to that measured on balloons in the polar ionosphere (Mozer et al. 1974), the magnitude of the model field was found to be larger than the measured one by an average factor of 3 (due to several simplifying assumptions adopted in the model), whereas the measured temporal variations were well reproduced by the model. Figure 1 shows the hourly values of the B_x, B_y and B_z components of the IMF used in the model, as well as the measured and computed electric fields for the period of September 4-6 of 1971 (Gonzalez, 1973; Gonzalez and Mozer, 1974).

In an attempt to search for an influence of the B_x component of the IMF in the process of magnetopause reconnection and, consequently, in the related convection-electric field, we have examined possible correlations between the amplitude of B_x and the measured electric field, shown in Figure 1, for several combinations of B_z and B_y during an away sector of the IMF.

Although there is no indication of a general influence of B_x on the whole measured electric field, there is some evidence that large measured fields occurred when B_x was small and vice versa. This influence, shown in Figure 2, was found for the time interval between 17:00 hours UT of September 4 and 22:00 hours UT of September 5 of the data shown in Figure 1. During this interval, the IMF remaided with an away polarity and the measured electric field had positive values. Furthermore, we selected cases when $B_z \leq 0$ and the transverse component of the IMF ($B_t \equiv \sqrt{B_y^2 + B_z^2}$) had values of 6 (± 1) gammas. The restriction $B_z \leq 0$ follows from the assumption that only magnetopause reconnection on non polar geomagnetic field lines contribute effectively to magnetopause convection with a larger potential the more southward B_z is (Gonzalez and Mozer, 1974; Nishida, 1978). A similar study for $B_z > 0$ does not show any clear dependence of the measured field on B_x except as discussed below. The approximately constant values of B_t reduce the probability that the influence shown in Figure 2 could also be due to the already known influences of B_z or/and B_y.

Since there is no solar wind speed data for the selected time interval, we have assumed a constant value for the solar wind speed. Although a sudden commencement occurred few hours in advance of the selected time interval, initiating a moderate storm, the K_p values during the whole time interval remained fairly constant. Thus, for the computation of the electric field discussed below we have used a constant solar wind speed equal to 300 Km/sec as in the work of Gonzalez and Mozer (1974). A somewhat higher and more realistic value would only change the amplitude of the computed field through a multiplicative factor without any appreciable change in the correlation presented in Figure 2 (Gonzalez, 1973).

Thus, the type of the B_x - effect suggested by Figure 2 is such that large convection-electric fields occur when B_x is small, and vice versa, and that changes in B_x from 2 to 8 gammas can account for as much as a factor of two decrease in the magnitude of the convection electric field when B_t (with sufficiently large values) and the solar wind speed are approximately constant. This influence was obtained for a set of reasonably large values of B_t (5 to 7 gammas) which are expected to produce large convection electric field magnitudes when $B_z \leq 0$ (Gonzalez and Mozer, 1974). For other values of B_t (except for the set with $B_t \leq 3$ gammas discussed below) it was not possible to find enough cases in order to have any clear indication of a similar influence of B_x on the measured field. When $B_t \leq 3$ gammas, as in the case (labeled 4) that refers in Figure 1 to the reasonable large period of time between 08:00 and 16:00 hours UT of September 4, there is an indication, both, in the measured and in the model field that reconnection ceases. This is attributed in part to the threshold for reconnection given by Gonzalez and Mozer (1974).

The following particular cases in Figure 1 illustrate the type of the B_x influence on the measured field described above. Cases 1a (September 5 at 10.00 UT) and 1b (September 5 at 21:00 UT) show small measured field values in the presence of a large B_x, although from the sufficiently large amplitudes of B_y and negative B_z one could have expected to measure bigger fields. Cases 2a (September 4 at 19:00 UT), 2b (September 5 at 05:00 UT) and 2c (September 5 at 18:00 UT) show the largest measured electric field values in the presence of small B_x and large negative B_z. Case 3 is an interesting example of a large measured electric field in the presence of a small value of B_x, with $B_z = 0$ and large B_y. This latter case advocates the importance of B_y in magnetopause reconnection and the consequent tilt of the reconnection line (Gonzalez and Mozer 1974). If the reconnection line would not tilt, the effective component of the interplanetary electric field along that line and the related measured electric field would be zero.

For the cases with $B_z > 0$, it was not possible to obtain a clear indication of an influence of the B_x component of the IMF on the measured electric field. However, for the several hours between the end of September 5 and the beginning of September 6, during which B_z was steadily northward, it is noted that the reversed polar cap electric field (dusk to dawn) becomes bigger when B_x gets smaller and vice versa. Thus, the type of the influence of B_x on magnetopause reconnection for $B_z > 0$ seems to be of the same nature as for $B_z \leq 0$. Namely, large values of B_x tend to reduce the magnitude of the convection electric field and vice versa. Nevertheless, the K_p values registered for this time interval indicate a recovery of the previous moderately stormy period. Therefore, changes in the solar wind speed (not registered), if appreciable, could have obscured the B_x effect for this case.

The above described B_x effect has been incorporated in a revision of the Gonzalez and Mozer (1974) model for magnetopause reconnection (Gonzalez 1979). Some of the basic features of the revised model are the following.

When B_x is small of absent within the magnetosheath, it was assumed in the model of Gonzalez and Mozer (1974) that the magnetosheath field lines approach the dayside magnetopause in a plane transverse to the Sun-Earth axis symmetrically with respect to the nose, and become tangent to the magnetopause boundary at the reconnection line. This line was assumed to form across the nose from one end to the other of the dayside magnetopause region where reconnection is expected to occur. When B_x is sufficiently large, the validity of this assumption is now questioned, since the magnetosheath field lines may become inclined with respect to the Earth-Sun axis and approach the magnetopause on effectively smaller regions off the nose. These regions are expected to lie basically above (below) the nose for positive (negative) values of B_x, when $B_z \leq 0$, giving rise to a north-south asymmetry in magnetopause reconnection. When this asymmetry is added to the already know dawn-dusk asymmetry, associate to $\pm B_y$, four quadrants on the dayside magnetopause are indentified as geometrically more appropriate regions for reconnection, with one of them favoured by one of the combinations of $\pm B_x$ and $\pm B_y$ when $B_z \leq 0$. It is assumed that the reconnection line still froms across the nose and pass through two of the four quadrants (one in each hemisphere), and, that the section of this line, which lies on the most favoured quadrant, involvs more intense currents and flows matched to those at the other quadrant via suitable field aligned currents and shear flow structures. When $B_z > 0$, one expects that reconnection involving polar geomagnetic field lines could still occur at suitable stagnation regions closer to the cusps (Maezawa, 1976) and with similar north-south and dawn-dusk asymmetries, according to the combinations of $\pm B_x$ and $\pm B_y$. This mode of reconnection could result eventually in a reversed polar cap convection (dusk and dawn electric field), as mentioned above.

Thus, when B_x is sufficiently large, one expects that the main consequence of the related shrinkage in the effective area of the assumed region of reconnection on the dayside magnetopause and of its position off the nose, might be a shortening of the reconnection line with a consequent reduction of the reconnection potential along it, and a shift of a more effective geometry for reconnection from the nose to higher latitudes, even when $B_z \leq 0$.

In order to incorporate the B_x - effect in the revised model for the reconnection potential (Gonzalez, 1979), it was found that the increase in the amplitude of both, B_x and B_y, contribute to an effective reduction of the potential. Thus, it was found that an appropiate expression for the revised potential is that given by Gonzalez and Mozer (1974) when modified by a removal of the geometrical factor (then introduced to take into account the fact that the dayside magnetopause is more oblate than a sphere) and by an insertion of the multiplicative factor $\bar{B}\phi/B\phi$, with $B\phi \equiv \sqrt{B_x^2 + B_y^2}$ and $\bar{B}\phi$ a normalizing average value of $B\phi$. For the data considered here and collected during about two days, it was computed $\bar{B}\phi \equiv 6$ gammas. It was also found that the factor $\bar{B}\phi/B\phi$ reduces the overestimation of the role of B_y (implied by the multiplicative factor $B_t \equiv \sqrt{B_z^2 + B_y^2}$) in the expression for the reconnection potential given by Gonzalez and Mozer (1974) and, therefore, represents mainly the B_x-effect suggested by the type of influence shown in Figure 2. Thus, the modified reconnection potential (in gaussian units) as given by Gonzalez (1979) is:

$$\Phi = \frac{2}{c} VR\, B_t \left(\frac{\bar{B}\phi}{B\phi}\right) F$$

Where, V is the solar wind speed, R the dayside magnetopause radius at the nose and F the function introduced by Gonzalez and Mozer (1974) to represent the effective projection of the interplanetary electric field $\left(\frac{V}{c} B_t\right)$ along the reconnection line. The direction of the reconnection line was assumed to lie along the direction of the current produced by the antiparallel components of the reconnecting fields.

This revised model for the reconnection potential has been used to simulate the measured ionospheric electric field (dotted curves in Figures 1 and 2) and is shown as the full curve in Figure 3. The Gonzalez and Mozer (1974) model gave the simulated field shown as the full curve at the botton of Figure 1. Not only the correlation coefficient raised from 0.69 to 0.81, but, the overestimation in the magnitude of the field also decreased from a factor of about 3 to a factor of only 1.4 or so. These factors refer to a solar wind speed of 300 km/sec used both in the work of Gonzalez and Mozer (1974) and in the present work. As mentioned above, a more realistic value would be somewhat higher (not available) and more representative of a moderately stormy period. In that case, we expect that only the overestimation factors (3 and 1.4) would become somewhat higher but the correlations between the measured and simulated electric fields would not basically change (Gonzalez, 1973).

Therefore, we suggest that the B_x component of the IMF plays an important role in magnetopause reconnection. Probably, the role of B_x has been implicitly included in previous studies, which accounted only for the influence of B_y (in addition to B_z), since both components are intimately related by the $B\phi$ component of the IMF along the average Archimedean spiral direction. The importance of the spiral component of the IMF is effectively incorporated in the model of Gonzalez (1979) with a consequent modulation of the length of the reconnection line that results in a model potential that agrees better with the observed polar ionospheric electric field.

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FIGURE CAPTIONS

Figure 1 - The top three panels show hourly values of the B_x, B_y and B_z components of the Interplanetary Magnetic Field (in Gammas) for the period of Sepember 4-6, 1971. The bottom panel shows hourly values of the measured (dotted line) and computed (full line) ionospheric electric fields at the polar cap (in mV/m), for the same period. Taken from Gonzalez (1973).

Figure 2 - Amplitude of the B_x component of the Interplanetary Magnetic Field (in Gammas) as a function of the measured electric field (in mV/m), during an away sector ($B_x < 0$), with $B_z \leq 0$ and $B_t \equiv \sqrt{B_y^2 + B_z^2} = 6(\pm 1)$ Gammas.

Figure 3 - Measured and computed electric fields (as in Figure 1) from the modified model by Gonzalez (1979) that takes into account the B_x-effect.

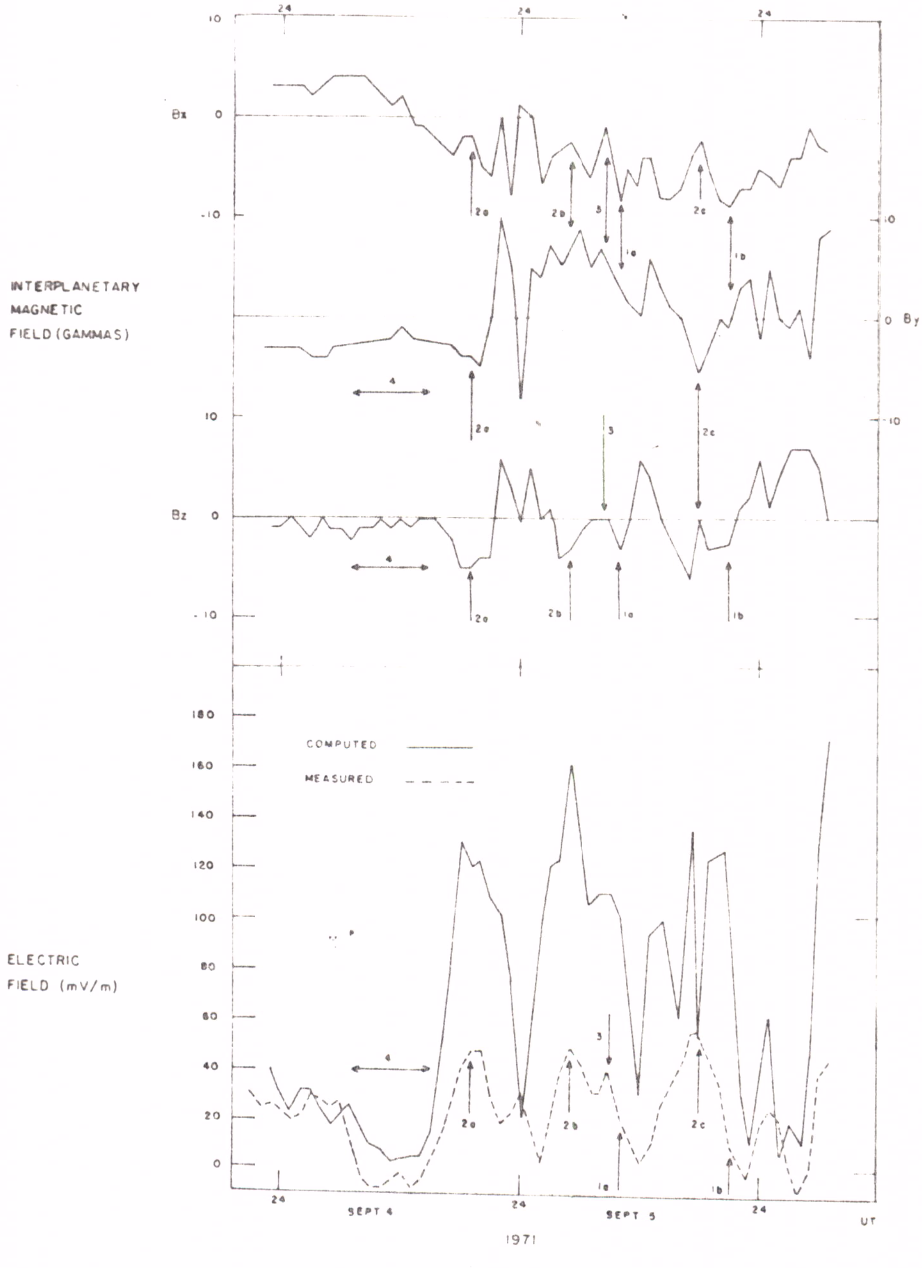

INTERPLANETARY
MAGNETIC
FIELD (GAMMAS)
Bx
By
Bz
ELECTRIC
FIELD (mV/m)
COMPUTED
MEASURED
SEPT 4
SEPT 5
1971
UT

Fig. 1

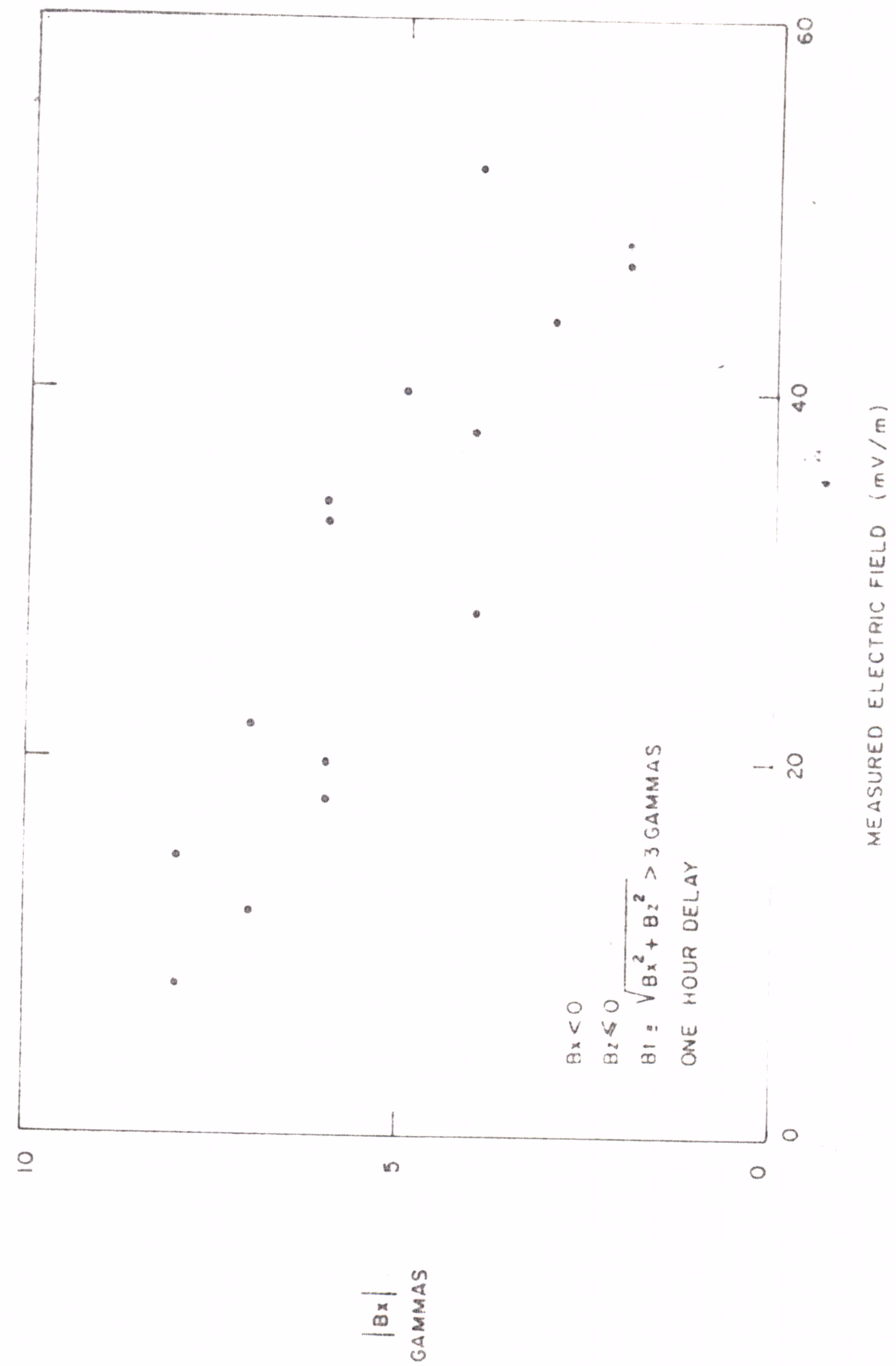
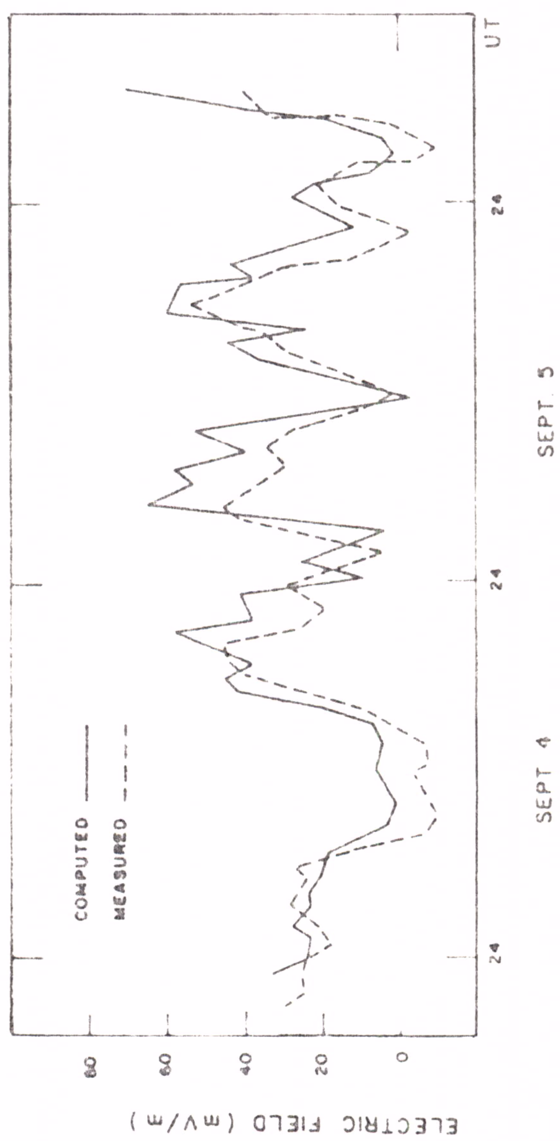

10
5
0
|Bx|
GAMMAS
0
20
40
60
MEASURED ELECTRIC FIELD (mV/m)
Bx < 0
Bz ≤ 0
BI = $\sqrt{Bx^2 + Bz^2}$ > 3 GAMMAS
ONE HOUR DELAY

Fig. 2



COMPUTED
MEASURED
ELECTRIC FIELD (mV/m)
80
60
40
20
0
24
24
24
SEPT 4
SEPT 5
UT

Fig. 3