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# An explanation for anomalous equatorial ionospheric electric fields associated with a northward turning of the interplanetary magnetic field

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# AN EXPLANATION FOR ANOMALOUS EQUATORIAL IONOSPHERIC ELECTRIC FIELDS ASSOCIATED WITH A NORTHWARD TURNING OF THE INTERPLANETARY MAGNETIC FIELD

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**Abstract.** Anomalous reversals of the zonal equatorial electric field component have sometimes been observed when the interplanetary magnetic field turns northward from a steady southerly direction. We suggest that this reversal is associated with a sudden change in the convection electric field in the magnetosphere and present measurements to support this explanation. Although slower variations in the convection field are shielded from the low latitude ionosphere by polarization charges at the inner edge of the ring current, these charges may require an hour or more to vary. A sudden decrease in the cross-tail electric field will thus be accompanied by a dusk-dawn perturbation electric field across the inner magnetosphere.

## Introduction

A number of studies based upon magnetometer data have indicated an electrical coupling between magnetospheric processes and the equatorial ionosphere (Onwumechili and Ogbuehi, 1962; Nishida, 1968, 1971; Onwumechili et al., 1973). Recently the data set has been expanded to include electric field measurements. The most extensive studies of this type have been compiled by Fejer et al. (1979) and Gonzales et al. (1979). They used electric field measurements from the Jicamarca Radar Observatory along with supporting data from worldwide magnetograms, from interplanetary probes, from balloon borne sensors, and from high latitude incoherent scatter stations, to study the variety of disturbances which affect the electrical structure of the equatorial region in disturbed times.

One of the intriguing aspects of this study involves the role of the interplanetary magnetic field (IMF) and, in particular, the sign of the component,  $B_z$ , anti-parallel to the Earth's magnetic dipole. Nishida (1968) first showed evidence for a relationship between the IMF and equatorial magnetic field variations, and further work was done by Rastogi and Patel (1975) and Patel (1978). The most detailed study is that of Fejer et al. (1979) who used eight years of Jicamarca measurements. Contrary to some results of Patel (1978), Fejer et al. showed that on the average the effect of the IMF on the vertical electric field component in the Peruvian equatorial region is negligible and the effect on the zonal component barely detectable, if present at all.

On the other hand, rapid changes in the IMF do seem, on occasion, to have related effects in the equatorial ionosphere. In this paper we discuss one class of such variations, a rapid turning of  $B_z$  from a low or southward value to a strong northward orientation first pointed out by Rostogi and Patel (1975).

## Discussion

Several examples of equatorial east-west electric field reversals associated with IMF northward turning were published in the literature (Rastogi and Patel, 1975; Patel, 1978; Fejer et al., 1979). An example of this phenomenon is presented in Figure 1, reproduced from the study by Fejer et al. (1979). This event has also been investigated in detail by Caan et al. (1977). The  $B_z$  component was steadily southward from about 0145 to 0400 when it rapidly switched sign. A substorm in progress, as indicated by the AU and AL indices in the lower plot, immediately entered a recovery phase. The westward E-region equatorial electron drift velocity shown in the upper panel, known to correlate well with the zonal electric field component (Balsley and Woodman, 1969), also reversed from its normal nighttime sense, to the opposite direction. Several examples of this type were discussed by Rastogi and Patel (1975). Caan et al. (1977) showed that if a rapid change from a steadily southward  $B_z$  to a northward value occurs during the course of a magnetospheric substorm, the event usually terminates. This was the case shown in Figure 1.

Rastogi and Patel (1975) suggested that the eastward nightside perturbation in the zonal equatorial electric field was due to a direct penetration of the interplanetary electric field throughout the magnetosphere and, in particular, to the equatorial ionosphere. The direction predicted by this explanation is correct since with  $B_z$  north, the interplanetary electric field has a  $z$  component directed dusk to dawn in the Earth's reference frame. This would be eastward near midnight on the nightside as observed. However, direct penetration of this electric field is difficult to reconcile with present understanding of the electrical properties of the magnetosphere. Considerable evidence exists that during southward  $B_z$ , the interplanetary field directly couples to large regions of the polar cap (see reviews by Russell and McPherron, 1973, and Vasyliunas, 1975) causing anti-sunward convection. The sunward flow in the auroral oval is a response to magnetic stresses and its detailed nature depends upon the energetic particle content of the plasma sheet and ring current and the coupling of this flowing plasma to the conducting ionosphere. When  $B_z$  is north, theory (Russell, 1972) and experiment (Burke et al., 1979) indicate that reconnection still can occur but is limited to the flanks of the polar cap and direct penetration of the interplanetary electric field is limited to this narrow latitude region. In neither case is the interplanetary electric field directly impressed across the low latitude, low altitude magnetosphere. We suggest here another explanation for the observed eastward nighttime electric field perturbation during

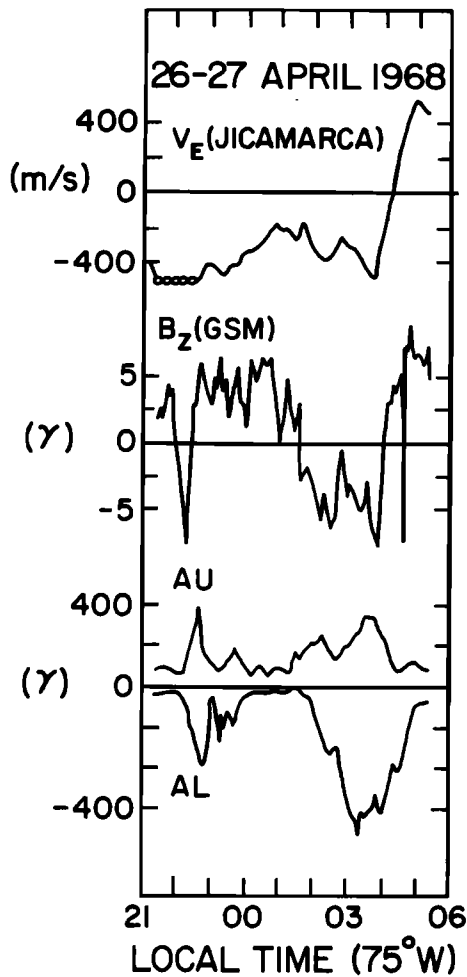


Fig. 1. E region electron drift velocity,  $B_z$ , and the auroral indices AU and AL during the evening of 26-27 April 1968 (after Fejer et al., 1979).

rapid northward turning of  $B_z$ . Note first, that some anomalous equatorial electric field patterns are related to substorm and ring current systems and have been explained as partial closure of such currents at low latitudes (Gonzales et al., 1979). This effect often occurs during extended periods of southward  $B_z$  (Fejer et al., 1979) and will not be discussed here.

When momentum exchange occurs between the solar wind and the magnetosphere due either to reconnection or viscous interaction, a dawn to dusk electric field exists on closed field lines deep in the magnetosphere and results in sunward convection. This field is shielded from the plasmasphere by charges located at dawn and dusk near the inner edge of the ring current (Vasyliunas, 1972). Thus the two sources of electrical field cancel and inside the plasmasphere the resulting electric field is that due to co-rotation. In the earth fixed frame this co-rotation field vanishes and the quiet time electric field is caused by tides and thermospheric winds. We contend that the magnetosphere was in an electrical configuration such as this during the substorm on 27 April 1968, which commenced at 0145 as shown in Figure 1. When the IMF abruptly turned northward, we suggest that the high latitude electric field driven by re-

connection decreased very quickly. This decrease is very likely related to the substorm recovery. Without the external electric field, however, the shielding charges will still be a source of dusk to dawn electric field in the inner magnetosphere. This results in an eastward perturbation field on the nightside. A westward perturbation is predicted on the dayside which would tend to suppress the equatorial electrojet. According to Vasyliunas (1972) the inertia of the ring current can maintain these shielding charges for a time scale of several hours. The effect is most easily seen in the zonal electric field measured at Jicamarca since the quiet time value is less than 1 mV/m and yet is reliably measured with the radar system. This is comparable to the magnetospheric field in the equatorial plane and hence can be observed as a large perturbation.

Evidence for the validity of this concept is presented in Figure 2 where we have plotted AU, AL, and the z-component of the IMF along with electric field data obtained from three incoherent scatter radar sites on 14 April 1978.

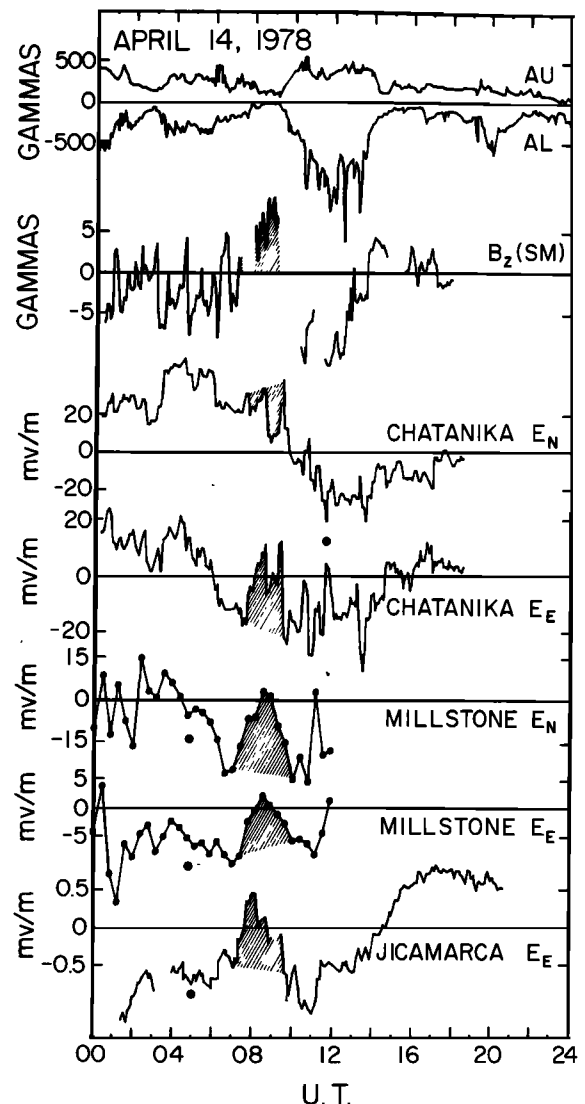


Fig. 2. Electric field data from two auroral zone and one equatorial site along with IMF and auroral activity indices for 14 April 1978.

Magnetic midnight is indicated with a dot for each observatory. The time of interest is shaded in the electric field data. At this time Chatanika was west of the Harang discontinuity and, prior to the event, had a strong north westward electric field. Millstone Hill was well past midnight and detected a south westward field. The Millstone Hill data plotted was from  $L=4.5$  but a nearly identical pattern was observed at Millstone for the entire range from  $L=4.5$  to  $L=7$  (Gonzales, 1979). Both data sets thus represent auroral electric field variations and both show a rapid decrease in convection electric field commencing around 0740 and lasting for almost two hours. Simultaneous with this decrease was an eastward perturbation in the zonal component at Jicamarca as predicted in the model described above.

Five minute averages of the IMF data are also plotted in the Figure. The sudden decrease in convection observed at Chatanika and Millstone Hill was closely correlated with the strong northward turning of the IMF. These data are thus in excellent agreement with the present explanation for the relationship between the Jicamarca electric field and the IMF. The modest substorm activity at this time ended as in the example plotted in Figure 1. Later when B turned southward, strong convection resumed, the equatorial field returned to its prior value, and a large substorm commenced later in the event. This substorm was also simultaneous with a dayside equatorial perturbation at Jicamarca (Gonzales et al., 1979) of the type they associate with partial closure of high latitude current systems at low latitude.

Gonzales et al. (1979) have also presented examples of events wherein magnetospheric convection suddenly increased. In such events, they interpreted the observed equatorial perturbation as due to direct penetration of the convection field, prior to the build-up of the shielding charges in the inner magnetosphere. This is, conceptually, very similar to the effect discussed in this paper when convection suddenly decreases.

The key link between equatorial perturbations and the IMF is thus the magnetospheric electric field and the state of the ring current. If IMF changes trigger large scale rapid changes in convection, then effects may be detected at low latitudes. If no corresponding convection change occurs, the IMF change will not be detectable near the earth. More examples and a more detailed discussion of these phenomena are presented by Fejer et al. (1979) and Gonzales et al. (1979).

#### Summary

Rapid reversals of the interplanetary magnetic field from steadily southward to steadily northward during substorm activity are often associated with anomalous reversals of the zonal electric field component at the equator. We suggest here that such an IMF change may quickly reduce the convection electric field on closed magnetic field lines inside the magnetosphere. The charges at the inner edge of the ring current which shield the low latitude magnetosphere from the convection field are thus temporarily out

of balance with the new electrical structure of the system and cause the observed dusk-dawn perturbation.

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