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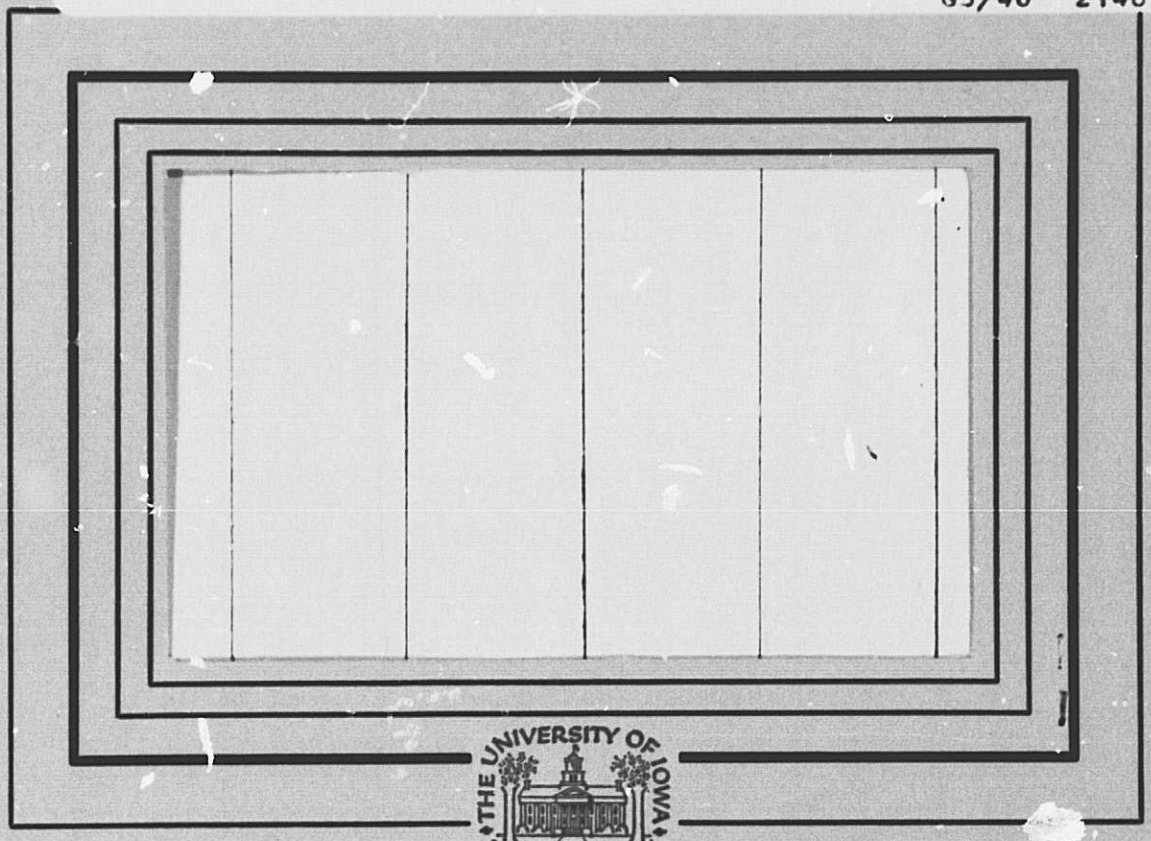

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A MODEL FOR POLAR CAP ELECTRIC FIELDS

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ABSTRACT

A model is proposed relating polar cap ionospheric electric fields to the parameters of the solar wind near the orbit of the earth. The model ignores altogether the notion of field line merging. An essential feature is the role played by velocity shear instabilities in regions of the outer magnetosphere, in which "mapping" of the magnetosheath electric field would produce sunward convection. The "anomalous" resistivity which arises from velocity shear turbulence, suffices to essentially "disconnect" the magnetosphere from the magnetosheath, at any place where that resistivity is large enough. The magnetosheath-magnetosphere system, as a consequence, acts as a kind of "diode" or rectifier for the magnetosheath electric fields.

Predictions of the model are compared with several observations related to polar cap convection.

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1. INTRODUCTION

Statements have appeared in the literature, within the last several years, to the effect that abundant evidence accumulated from various quarters makes it inevitable (or nearly so) to accept merging of interplanetary magnetic fields with the earth's field as the dominant (if not the only) process responsible for convection in the polar caps and surrounding regions.

The mere number of such statements from authoritative sources seems at first sight to be so overwhelming, that any attempt at explaining magnetospheric convection on a basis other than merging would be regarded, at best, as a futile exercise.

On the other hand, observational evidence has also been presented which is not easy to reconcile with the idea of merging. A few examples are listed below.

Heppner (1972) notes that the polar cap electric field patterns observed by OGO 6 have "little in common" with predictions based on current field line merging mechanisms.

A study by Mencke Hansen et al. (1976), of several HEOS-2 passes through the distant cusp-magnetosheath interface shows much better agreement with closed magnetosphere models than with open (merging) models.

Michel and Dessler (1975) discuss the penetration of low-energy cosmic particles to the polar caps and arrive at the conclusion that, what has long been regarded as one of the most important pieces of

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evidence in favor of an open magnetosphere model does not, after all, favor an open more than a closed model.

Thus, trying to understand certain high-latitude observations (particularly in the polar cap) on the basis of a (magnetically) closed magnetosphere model may not seem such a futile exercise, as one would have been led to believe. In the present paper an attempt is made at explaining a number of observations related to polar cap electric fields, by entirely ignoring the notion of magnetic field line merging. The plan of this paper is as follows. In Section 2 a model (based on a closed magnetosphere) is proposed for polar cap electric fields and their relation to parameters in the solar wind near the orbit of the earth. Certain predictions are formulated, which are then compared with polar cap observations in Section 3. Section 4 contains a discussion and Section 5 the conclusions.

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2. THE MODEL

In this section a model is presented, which should help relating polar cap ionospheric electric fields to the parameters of the solar wind near the orbit of the earth. The predictions of the model are then compared with observations in Section 3. It should be understood that what we are primarily concerned with here are the gross and more outstanding features of observations related to polar cap electric fields and convection. Thus the present model lacks that sophistication which can only be brought about by further studies to be undertaken in the event the model proves to be of sufficient interest and significance.

Consider a cut of the earth's magnetosphere and magnetosheath with a plane near the dawn-dusk meridian, as shown in Fig. 1. The situation this figure refers to is one in which the y component, B_y, of the solar wind magnetic field is positive ("away" sector). The magnetic field lines issuing from the earth are "swept back" to the tail in the vicinity of the magnetopause. No component of $\underline{B}$ normal to the magnetopause is assumed to exist in line with observational evidence indicating that, although a normal component of $\underline{B}$ at the magnetopause has been looked for, none has been found, in an average sense, and beyond reasonable doubt [e.g., Mencke Hansen et al. (1976)].

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At the magnetopause-magnetosphere transition two types of regions will generally have to be considered, indicated schematically by "A" and "P" (and shaded areas) in Fig. 1. In "A" type regions the earth's field and the magnetosheath field are, on the average, roughly antiparallel; whereas in "P" type regions they are, on the average, roughly parallel.

Let the magnetosheath electric field, $\underline{E} = -\underline{V} \times \underline{B}$, have components $E_x = 0$, $E_y = -V B_z$, $E_z = V B_y$ in a GSM reference frame (for the particular case indicated in Fig. 1, $E_y = 0$). Since the component of the magnetosheath electric field normal to the magnetopause may be "shielded" by charges accumulated on the magnetopause, we concern ourselves only with the component of the magnetosheath electric field which is tangential to the magnetopause. Restricting consideration to the tangential component alone is further justified by our procedure of computing the total potential difference between the center of the cap and its dawn or dusk edge (see below in this section). From

$$\nabla \times \underline{E} = - \frac{\partial \underline{B}}{\partial t} \qquad (1)$$

and the further condition that the long time average of $\frac{\partial \underline{B}}{\partial t}$ be equal to zero, it follows that the tangential component of $\underline{E}$ will be conserved upon crossing the magnetopause, provided no "resistive" voltage drops of any significance occur across the magnetosheath-magnetosphere transition region. We shall assume that this is the case in "P" type regions, where the magnetosheath electric field is

thus "transmitted" across the magnetopause and is mapped down to the ionosphere, suitably amplified (by an average factor ~ 20) by convergence of the magnetic field lines. Note that in "P" type regions the condition that the tangential component of $\underline{E}$ be conserved upon crossing the magnetopause, entails that on either side of the magnetopause the plasma flow be in the same direction, i.e., tailward. In "A" type regions, on the other hand, conservation of the tangential component of $\underline{E}$ would bring about a magnetospheric plasma flow which is sunward, i.e. in opposite direction to the magnetosheath flow. Its magnitude may be large and often comparable to that of the magnetosheath flow. Thus, a situation would arise in which a very large relative velocity, up to ~ 800 km/sec or so, between two plasma layers, one just outside and one just inside the magnetopause, may exist. Such a situation must generally be highly unstable to velocity shear instabilities, with the conclusion that "A" type regions are thus far more prone to phenomena of "enhanced" or "anomalous" resistivity (and plasma heating) than "P" regions are. One can thus envisage a mechanism which, by producing a large "anomalous" resistivity in "A" type regions, effectively "disconnects" the magnetospheric "A" regions from the adjacent regions in the magnetosheath. For such a mechanism to be of any significance, the resistance to current flow across the magnetoapuse, in "A" type regions, must be comparable to or higher than the resistance the currents encounter in flowing north-south in the ionosphere. A comparison can be made by computing the ionospheric resistance from the height integrated Pedersen resistivity,

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and by estimating the "anomalous" resistance at the magnetopause by using Buneman's formula [Buneman (1959)]. There is no doubt that this type of argument is subject to large uncertainties. The most reasonable numerical estimates, however, indicate (with $\eta_B \sim \frac{m_e \nu_{eff}}{n\, q^2}$; $\nu_{eff} \sim 10^{-2}\omega_{pe}$ and $n \sim 10\ cm^{-3}$) that, for strong turbulence at the magnetopause, "A" type magnetospheric regions should be effectively "disconnected" from adjacent magnetosheath regions. As a consequence, the magnetosheath electric field cannot be mapped down to the ionosphere in the same manner in "A" type as in "P" type regions.

We thus conjecture that "mapping" of the magnetosheath electric field down to the ionosphere occurs predominantly from "P" type regions. The electric fields in those portions of the ionosphere which are connected to "A" type regions will generally be of a much smaller magnitude.

A simpler way, perhaps, to visualize the effect of the "disconnection" mechanism may be as follows. Any time the magnetosheath electric field "maps" into a sufficiently large dusk-to-dawn magnetospheric field, it produces turbulence by velocity shear. The consequent anomalous resistivity acts to reduce (or limit) the magnitude of the dusk-to-dawn field. Thus, the magnetosphere-magnetosheath system acts, as it were, as a kind of "diode" or rectifier for the electric field.

The next point to consider is the strength to be expected of the polar cap electric field where "mapping" from the magnetosheath occurs, and how this strength relates to the B_y and B_z components of the solar wind magnetic field. We refer for this purpose to Fig. 2, which again shows a schematic cut of the northern magnetosphere with

the dawn-dusk meridian plane. The northern polar cap extends from B to D, and C is the northern geomagnetic pole. With the assumption that the earth's magnetic field lines are equipotentials and by integrating the solar wind-magnetosheath electric field along the dotted line of length ~2L shown in the figure (or its counterpart on the dusk side), we may write for the voltage difference between B and C (or C and D)

$$\Delta V_{BC} = V\,L(B_y - B_z) = V\,L(|B_y| - B_z)$$

for $B_y > 0$, since in this case the dawn side magnetopause is of "P" type and

$$\Delta V_{CD} = V\,L(-B_y - B_z) = V\,L(|B_y| - B_z)$$

for $B_y < 0$, since in this case the dusk side of the magnetopause is of "P" type.

Thus for both $B_y > 0$ and $B_y < 0$, the dawn-to-dusk ionospheric electric field is proportional to $VL(|B_y| - B_z)$. Note that a positive value of the quantity in brackets, $(|B_y| - B_z)$, implies antisunward convection of the polar cap plasma. A negative value, if it occurs, would correspond to sunward convection.

An immediate consequence of the above arguments is that large antisunward convection is obtained when $B_z < 0$, since the two terms $|B_y|$ and $-B_z$ add in this case. For $B_z > 0$ convection velocities should be smaller and only when, for $B_z > 0$, B_z is also large enough to exceed $|B_y|$ may one expect to see some sunward convection.

It is also clear from a geometry of the type indicated in Fig. 2, that the largest ionospheric electric field intensities are to be expected near the equatorward boundary of the polar cap rather than near its center. To see this, it is sufficient to draw a few additional dipolar field lines, for instance on the dawn side, whose "feet", i.e. intersections with the ionosphere, are equally spaced in the north-south direction.

To summarize the contents of this Section, our model predicts: (a) For $B_y > 0$, the largest electric field intensities at ionospheric heights are to be expected on the dawn side of the northern polar cap (as well as on the dusk side of the southern polar cap). For $B_y < 0$, the largest ionospheric $\underline{E}$ fields should be observed on the dusk side of the northern cap (and on the dawn side of the southern cap).
(b) The ionospheric electric field strength is proportional to $|B_y| - B_z$ and is directed from dawn to dusk when this quantity is positive.

(c) The largest values of $|B_y| - B_z$ occur for $B_z < 0$, and it is on such occasions that the largest convection velocities should appear.
(d) Sunward convection may be observed when $(|B_y| - B_z) < 0$. A positive B_z is then required, and large enough to exceed $|B_y|$. In any case, the magnitude of the sunward convection velocity will generally be considerably smaller than typical values of the antisunward convection velocities.

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(e) The largest values of the ionospheric electric field strength should be found near the edge of the cap, rather than at its center. (f) Large velocity shears in "A" type regions should bring about plasma heating there. It is easy to convince oneself, by examination of the four different cases $B_y \gtrless 0$, $B_z \gtrless 0$, that the largest velocity shears occur in "A" type regions when B_z is sufficiently positive. In such cases, hot and stagnant plasmas may be found in "A" type regions of the magnetosphere next to the magnetopause.

Before we proceed to the next Section and compare our model with observations, it is worth adding a few remarks for the benefit of the reader who may feel unconvinced by our previous arguments. That reader may draw for himself a section of the magnetosphere, as in our Figs. 1 and 2, and note the following.

Begin by considering a magnetosheath magnetic field which is purely southward ($B_z < 0$, $B_y = 0$), to which a magnetosheath electric field is associated, which is directed dawn-to-dusk. Then proceed to turn the magnetosheath magnetic field counterclockwise until it is purely northward. Thus, one covers all cases for which $B_y > 0$ and B_z is of either sign (analogous remarks will apply for $B_y < 0$). For B_z purely southward, the entire cap is of "P" type and we thus expect antisunward convection all over it, the parallel (to the magnetopause) component of $\underline{E}$ being conserved upon crossing the magnetopause. As the magnetosheath $\underline{B}$ field is turned northward, the dawn side of the (northern) cap still remains of "P" type, while an ever increasing portion of the dusk cap becomes of "A" type. When,

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finally, the magnetosheath B field points purely northward, the entire cap is of "A" type. Thus, as B turns from purely southward to purely northward, that portion of the cap over which unhindered "mapping" of the magnetosheath electric field occurs (antisunward convection) shrinks to a smaller and smaller size towards dawn, while the size of the "A" type region grows.

By also keeping in mind that our "disconnection" mechanism prevents the sunward convection from ever growing too large, the chance of observing sunward convection must be seen to be largest for B_z large and positive.

3. OBSERVATIONS

In this Section we discuss several observations which directly relate to the model put forward in Section 2 and appear generally to support it.

3.1. Measurements of polar cap ionospheric electric fields by e.g., Heppner (1972) and Mozer et. al. (1974) have shown that, in general, the polar cap electric field is directed from dawn to dusk, has its maximum strength near the border of the cap, and is strong (in the northern cap) on the dawn side for $B_y > 0$ and on the dusk side for $B_y < 0$. Our model is clearly in agreement with these observations.

3.2 Friis-Christensen and Wilhjelm (1975) have presented maps of the polar cap currents for different directions of the interplanetary magnetic field. It is immediately obvious from inspection of their Figs. 1, 3, and 5 that the largest antisunward convection velocities occur almost exclusively for $B_z < 0$ (see our point (c), Section 2). Also, appreciable sunward convection is noticeable only for $B_z > 0$ (see our point (d), Section 2).

Figure 10 of Friis-Christensen and Wilhjelm (1975) shows a plot of hourly average values, from the 2000-2300 UT sector at Thule, of the horizontal component of the magnetic perturbation vector versus B_z for $B_z < -1\gamma$ and $B_z > 1\gamma$ ($B_y \gtrless 0$). Their Fig. 10 is reproduced here as our Fig. 3. From Tables 2, 3, and 4 of Friis-Christensen and

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Wilhjelm (1975) it is easily seen that B_y and B_z have, on the average, comparable absolute magnitudes. Thus, if the strength of the polar cap electric field is correctly predicted by our model in Section 2, we should expect, on the average, that $E \propto |B_y| - B_z$ be nearly zero and, of course, independent of B_z for positive B_z's, whereas $|E|$ should be proportional to $|B_z|$ for $B_z < 0$. That this is borne out by the observations is seen by inspection of Fig. 3.

In addition, a plot similar to the one in Fig. 3, but restricted to values of $B_y \sim 0$ ($-1.5\gamma < B_y < 1.5\gamma$), should not exhibit the characteristic "break" of Fig. 3 but should rather show a nearly linear relationship between the horizontal component of the ground magnetic perturbation and B_z. This appears indeed to be the case (Friis-Christensen, private communication), although the statistics are poorer than in Fig. 3.

3.3 In Fig. 4 the dawn-to-dusk component of the ionospheric electric field measured on balloons by Mozer and Gonzalez (1973) on September 3-6, 1971, at Thule is shown, together with the quantity ($|B_y| - B_z$) which we have constructed from Imp 5 data [Mozer and Gonzalez (1973)]. The correlation between the two curves is excellent. It is important to note, in particular, that <u>dusk-to-dawn</u> electric fields are measured when the quantity ($|B_y| - B_z$) is negative (see point (d) of Section 2). Although the early hours of September 6, 1971, are not covered by the Thule balloons, a balloon flight from Resolute Bay shows a clear sunward convection at that time [Mozer and Gonzalez (1973)].

3.4. Gonzalez and Mozer (1974), in a paper concerned with a quantitative model for the potential resulting from reconnection of the earth's magnetic field with an arbitrary interplanetary magnetic field, show in their Fig. 10 a comparison between hourly averages of the dawn-to-dusk component of the electric fields measured at Thule and Resolute Bay with the electric field computed from their model.

We shall comment on their model in the next section. For the moment, it seems instructive to make use of the observational data in their Fig. 10 and see whether anything can be learned which might be of relevance to our model in Section 2.

Gonzalez and Mozer (1974) divide their data into four ranges of α_o, the angle between the earth's magnetic field at the nose of the magnetosphere (the subsolar point) and the interplanetary magnetic field [$\tan \alpha_o = \frac{|B_y|}{B_z}$, $0° \leq \alpha_o \leq 180°$]. The observational data in Fig. 10 of Gonzalez and Mozer (1974) have been utilized to construct our Fig. 5. For each range of α_o [$0° \leq \alpha_o \leq 80°$, $80° \leq \alpha_o \leq 100°$, $100° \leq \alpha_o \leq 120°$, $120° \leq \alpha_o \leq 180°$] each hourly average of the average dawn-to-dusk component of the electric fields measured at Thule and Resolute Bay is shown by a horizontal dotted line. The four heavy lines represent the average electric field measured in each of the four α_o ranges. The dotted curve represents a quantity proportional to $|B_y| - B_z = B (\sin \alpha_o - \cos \alpha_o)$.

Several points of interest are noted in Fig. 5. The fit of the curve $B(\sin \alpha_o - \cos \alpha_o)$ vs. α_o to the averages of the measured

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electric field, for each α_o range, is satisfactory. Note that for any α_o, the observed spread of ionospheric E's is determined by the spread of the product VB in the solar wind. This latter quantity is known to vary by factors as large as 3-4 on time scales of several hours, as well as on longer time scales. The largest uncertainties in α_o should be present in those cases in which B (and thus the ionospheric electric field) is smallest. Significantly negative values of E (sunward convection) occur almost exclusively for $0° \leq \alpha_o \leq 90°$. The absolute magnitudes of the negative electric fields are considerably smaller, on the average, than the absolute magnitudes of the positive electric fields (see points (b)-(d) of Section 2). Note in particular, for comparison with other observations in Section 3.6, that the number of negative E occurrences in Fig. 5 is approximately 1/4 of the total number of occurrences.

3.5. The polar cap electric field model proposed in Section 2 has been successful in accounting for the observed relationship between pc2-4 micropulsation period and the parameters of the interplanetary medium at the earth's orbit. Russian micropulsation data (e.g. Troitskaya et al. (1971), Gul'elmi and Bol'shakova (1975), Gul'elmi et al. (1973), Gul'elmi (1974), can apparently be organized on the assumption that the observed pc2-4 micropulsation frequency is, in general, largely determined by Doppler shifts arising from $\underline{E} \times \underline{B}$ motions in the magnetosphere. This has been done by employing essentially the model in Section 2 [D'Angelo (1975)].

3.6. A recent paper by Sckopke et al. (1975) seems also very relevant to the polar cap electric field model proposed in Section 2.

Sckopke et al. (1975) have studied the response of the "plasma mantle" [Rosenbauer et al. (1975)] to the orientation of the interplanetary magnetic field by correlating HEOS-2 plasma and IMP-6 magnetic field data. According to them, "The mantle is nearly always present when the IMF has a southward component, and often also when the field has a weak northward component. In addition, the mantle appears increasingly thicker with greater southward components. On the other hand, the mantle is thin or missing (from the region where it is normally found) when the average IMF has a strong northward component. This result supports the idea that polar cap convection plays a dominant role in the formation of the plasma mantle: mantle plasma originates in the magnetosheath, enters the magnetosphere through the dayside polar cusps, and is transported across the cusp to the night side by means of a convection electric field whose magnitude is controlled by the orientation of the IMF". Also, "... a stronger convection electric field will carry the plasma deeper into the polar cap and will produce a thicker plasma mantle".

We note, first of all, that approximately 70% of the HEOS-2 passes through the distant polar magnetosphere tailward from the cusp have encountered mantle plasma in layers thicker than $\sim 0.5\ R_E$. In approximately 1/4 of the passes, the mantle plasma is missing. In this connection, we need only refer the reader to our discussion (Section 3.4) of the paper by Gonzalez and Mozer (1974)

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and, in particular, to the fact that (see our Fig. 5) the number of negative E occurrences is approximately 1/4 of the total number of occurrences.

Figure 1 of Sckopke et al. (1975) shows a plot of the mantle thickness vs. the z component of the IMF, B_z. This figure is clearly reminiscent of Fig. 10 of Friis-Christensen and Wilhjelm (1975) (our Fig. 3) and its significance can be related to that of our Fig. 3 and discussed through the same type of arguments we have used in Section 3.2. Skopke et al. (1975) remark that the fairly large scatter in their Fig. 1 may be due to the fact that B_z is, perhaps, not the most appropriate independent variable to use. It would certainly be of interest to know what a plot of mantle thickness vs. $(|B_y| - B_z)$ looks like.

One final point in the paper of Skopke et al. (1975) should be mentioned. They observe at times a "stagnant" and "hot" plasma in the mantle region when $B_z > 0$. The plasma is stagnant in the sense that it does not have a measurable tailward velocity, as most mantle plasma does, and its temperature may be as large as $\sim 10^7$°K. This finding seems to be in line with our mechanism for electrically "disconnecting" the "A" type regions of the magnetosphere from adjacent magnetosheath regions. We have invoked the "anomalous" resistivity, brought about by velocity shear instabilities, to reduce the magnetospheric electric field to negligible values ("stagnant" plasma). A further consequence of the instabilities should, of course, be also plasma heating (see point (f) of Section 2). The kinetic energy of the

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sheared plasma motion is converted into turbulence as well as into a higher random velocity of the plasma particles. A rough estimate of the temperature increase to be expected is obtained by assuming that, what would have been, in the absence of velocity shear instabilities, the energy of a sunward ordered motion with velocity $V_D \sim 300$ km/s, is used up to heat the plasma ions. Thus $\frac{1}{2} m_i v_D^2 \sim K\Delta T_i$ and $\Delta T_i \leq 10^7$°K, in agreement with observations. The "hot" and "stagnant" plasma, according to our model, may be seen in "A" type regions when B_z is sufficiently positive. Over a total of 21 magnetopause crossings, it has been observed in 3 cases [see Fig. 1 of Sckopke *et al.* (1975)].

4. DISCUSSION

The variation of the ionospheric electric field strength in the polar cap as a function of position of the earth within an interplanetary sector has been inferred by D'Angelo and Olesen (1975) on the basis of the occurrence of the Slant E Condition in polar cap ionograms. As a continuation of that work, Bahnsen and D'Angelo (1976) have studied the variation of the solar wind electric field near the earth, as a function of the earth's position within an interplanetary sector. Figure 3 of Bahnsen and D'Angelo is reproduced here as Fig. 6. The figure shows the time behavior, over a period of approximately 4 1/2 solar rotations, of the z and y components of the solar wind electric field (daily averages). The polarity of each solar wind sector is marked on the figure (black → "toward" sectors, white → "away" sectors). $E_z = V B_y$ has opposite sign in sectors of opposite polarity and its magnitude, $|E_z|$, maximizes 1-2 days after passage of a sector boundary, to decline more or less steadily in the trailing portion of each sector. On the other hand, $E_y = -V B_z$ fluctuates throughout the entire period of observation and <u>within each separate sector</u> around a nearly zero value.

The time behavior exhibited by $|E_z|$, but <u>not</u> by $|E_y|$, is of the type which had been inferred by D'Angelo and Olesen (1975) for the ionospheric electric field strength on the basis of the Slant E Condition observations. It is also the time behavior exhibited, as the earth moves from a sector of one polarity to another

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of opposite polarity, by the polar cap ionospheric electric field as actually measured, for an uninterrupted period of ~ 8 days and by means of balloons, by D'Angelo et al. (1976).

It thus becomes evident that, the long time behavior of the polar cap electric field strength being the same as the behavior of $|E_z| = |V B_y|$ but not of $|E_y| = |V B_z|$, the long time ($t \geq 1$ day) average of the polar cap convection velocity cannot result predominantly from the southward component of the solar wind magnetic field. This conclusion is clearly in contradiction with the idea of merging in the form originally proposed for the earth's magnetosphere by Dungey (1961). In that merging model, the dominant role, as far as polar cap convection is concerned, was assigned to B_z, B_y playing, in fact, not even a secondary role. Thus it seems appropriate not to comment further on Dungey's merging model, but rather concern ourselves with the more recent one of Gonzalez and Mozer (1974).

The merging model of Gonzalez and Mozer (1974) does take into account the observational results on polar cap electric fields obtained in recent years and is successful in several respects (see, for instance, Fig. 9 of Gonzalez and Mozer (1974), which is quite similar to our Fig. 4). The fact remains, however, that even this much improved merging model cannot apparently account for polar cap sunward convection, as Gonzalez and Mozer themselves explicitly point out. This partial failure is shown already in their Fig. 9, but most dramatically in the top two panels of their Fig. 10.

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The model proposed in the present paper is based on the notion of a (magnetically) closed magnetosphere. As it now stands, it contains in an essential manner the idea that, for a given sign of the interplanetary magnetic field component B_y, the solar wind-magnetosheath electric field can be "mapped" down to the ionosphere over roughly one-half of the cap. As for the other half, a mechanism has been invoked which should suffice to substantially disconnect it from the solar wind-magnetosheath. The mechanism chosen relies on an increase of the resistivity near the magnetopause, in what have been termed "A" type regions. Although this mechanism seems reasonable enough, until it is directly demonstrated by local turbulence measurements it may have the flavor of a somewhat "ad hoc" device. Were it to be disproved, however, any other mechanism which effectively disconnects "A" type regions from the solar wind-magnetosheath would also serve the same purpose and leave most of our other considerations and conclusions unchanged.

A possible objection to the "disconnection" mechanism that we have made use of in Section 2 is the following. Since this mechanism is supposedly setup by the high velocity shear which would accompany large sunward convection in the cap, how can one expect ever to see this sunward convection at all? The answer to this question may be found in the fact, already noted in Section 2 and Section 3, that the velocity of polar cap sunward convection is never very large.

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5. CONCLUSIONS

A model for the convection of plasma in the polar cap has been proposed. It makes use of the notion of a magnetically closed magnetosphere and, thus, avoids altogether the idea of magnetic merging. An expression for polar cap electric fields has been derived, in terms of the y and z components of the solar wind-magnetosheath magnetic field. The predictions of the model have been compared with polar cap observations. It appears that there is better agreement with observations than by using models based on the idea of magnetic field line merging. It is worthwhile to note specifically the following point. The correlation of large and negative B_z's with strong antisunward convection in the cap has very often been taken as a strong argument in favor of models based on the notion of magnetic merging. It is now clear that such a correlation may at least equally well be expected when the notion of merging is dropped altogether.

Two further tests of the ideas put forward in this paper may, finally, be envisaged:

(a) The polar cap electric fields measured by Gonzalez and Mozer (1974) at Thule and Resolute Bay (see, for instance, their Fig. 10) could be reanalyzed in terms of the quantity $(|B_y| - B_z)$ and by subdividing the entire $0° \leq \alpha_o \leq 180°$ range into, say. 10 or more intervals rather than the four intervals used in their analysis. The same could be done with any other available set of polar cap electric fields.

(b) The observations of a "hot" and "stagnant" plasma in the mantle region may be combined with observations of turbulence near the magnetopause. Enhanced turbulence should occur, for B_z sufficiently positive, in "A" type regions.

In conclusion, the following remarks may be in order. The model for polar cap electric fields, presented in Section 2, has concentrated on the situation prevailing in the vicinity of the dawn-dusk meridian, with the dipolar field lines being "swept back" into the tail (in agreement with observations). The possibility remains that, in so doing, also some problems or difficulties have been "swept" (back into the tail or "under the rug"). It would be clearly desirable to investigate these questions in a more complete analysis. In addition, the "disconnection" mechanism of Section 2 could conceivably be applied also to some form or other of open magnetosphere model, to see whether some of the difficulties encountered by these models (and touched upon in Section 4) may be removed.

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ACKNOWLEDGEMENTS

Useful comments by E. Friis-Christensen, C. Goertz, P. Kintner, and D. Montgomery are very gratefully acknowledged.

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FIGURE CAPTIONS

Fig. 1. A schematic cut of the earth's magnetosphere with the dawn-dusk meridian plane. The shaded areas indicate "A" type and "P" type regions.

Fig. 2. A schematic cut of the earth's magnetosphere with the dawn-dusk meridian plane. The voltage difference between A and F (F and E) is assumed to be the same as between B and C (C and D).

Fig. 3. Plot of hourly average values from the 2000-2300 UT sector at Thule of the horizontal component of the magnetic perturbation vector versus B_z, for $B_z < -1\gamma$ and $B_z > 1\gamma$ (from Friis-Christensen and Wilhjelm (1975)).

Fig. 4. a) The quantity $(|B_y| - B_z)$ versus time, obtained from the IMP 5 data reported by Mozer and Gonzalez (1973).
b) The dawn-to-dusk electric field (mV/m) measured at Thule by means of balloon borne sensors by Mozer and Gonzalez (1973).

Fig. 5. Hourly averages of the dawn-to-dusk ionospheric electric field at Thule and Resolute Bay (dotted lines) versus α_o, the angle at the nose of the magnetosphere between the earth's field and the IMF. The four heavy lines are th average electric field measured in each α_o range. The ordinate of the dotted curve is proportional to $(\sin \alpha_o - \cos \alpha_o)$. The measured electric fields are from Fig. 10 of Gonzalez and Mozer (1974).

Fig. 6. Daily averages of the two components of the solar wind electric field, E_y and E_z, measured on HEOS-2, April through July 1974. The solar wind sector structure, determined directly by the satellite magnetometer, is indicated in black for toward sectors, white for away sectors. Sudden commencements are indicated by black triangles [from Bahnsen and D'Angelo (1976)].

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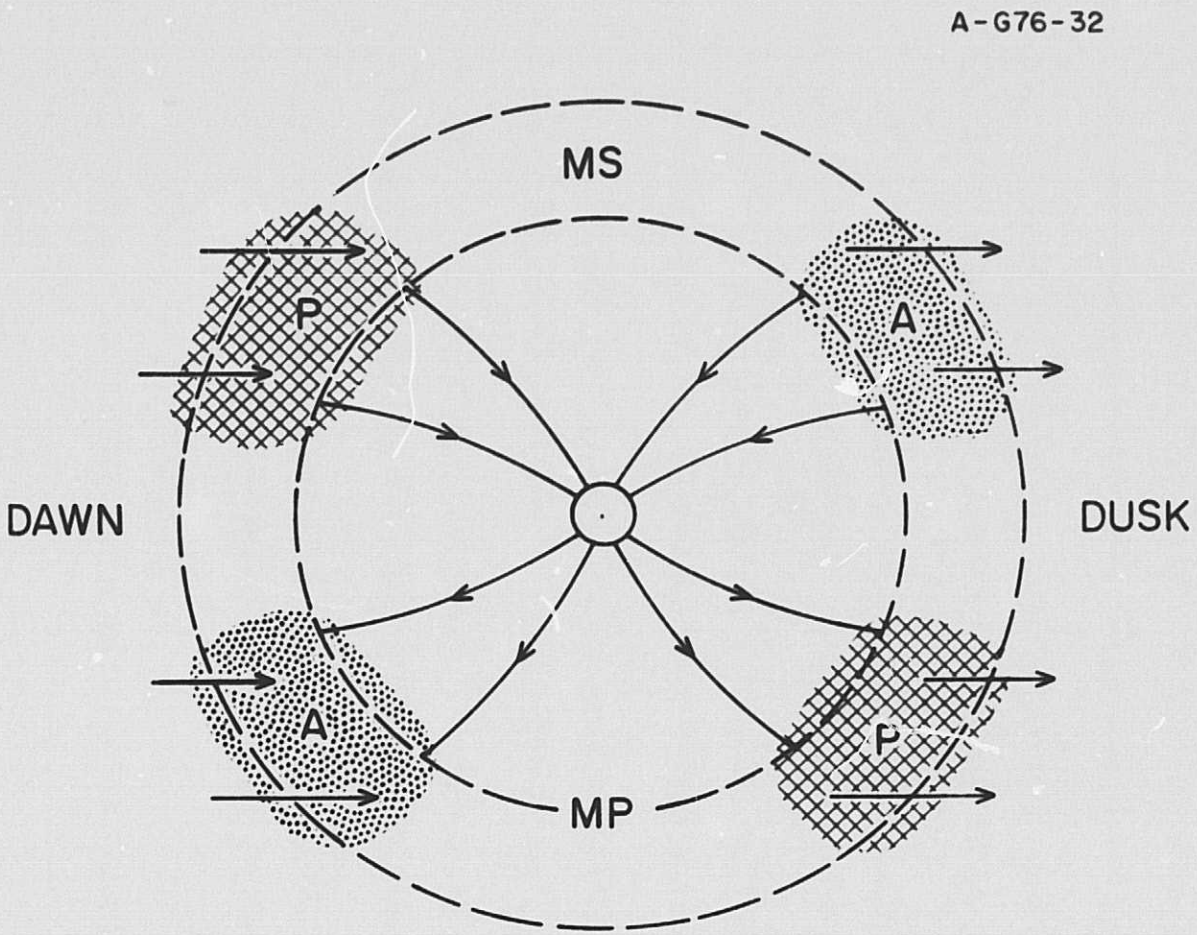

Figure 1

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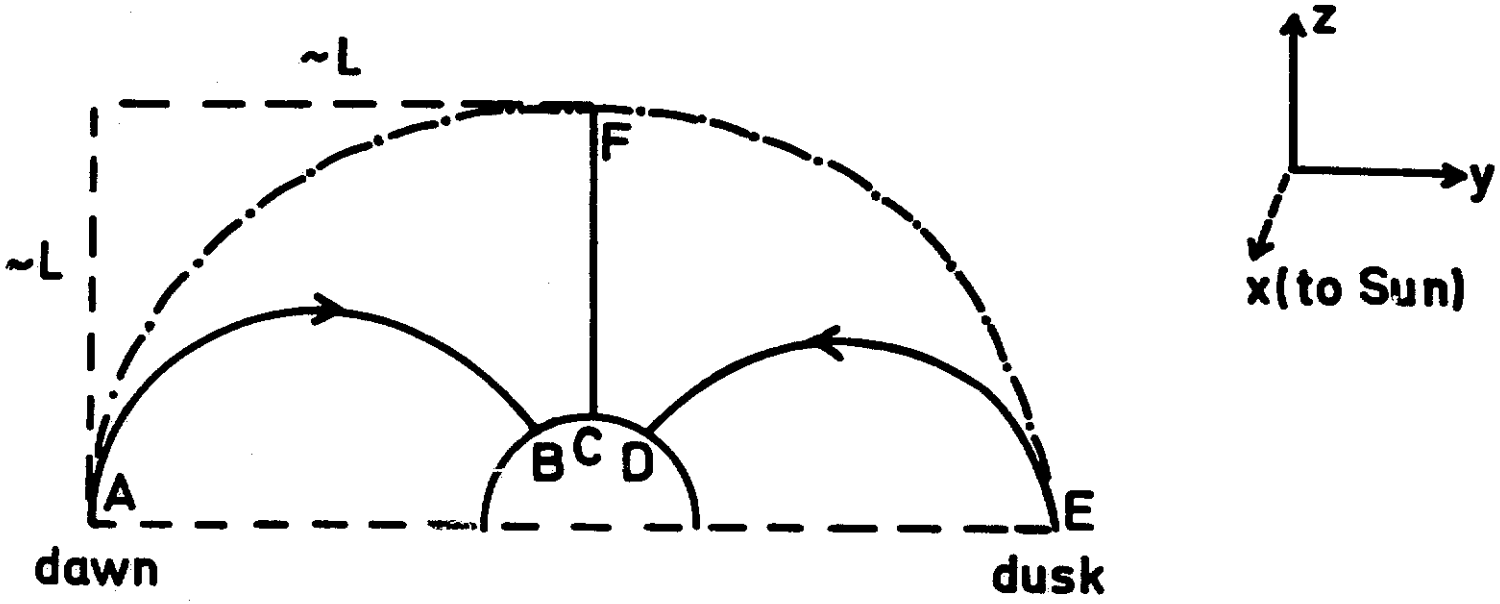

Figure 2

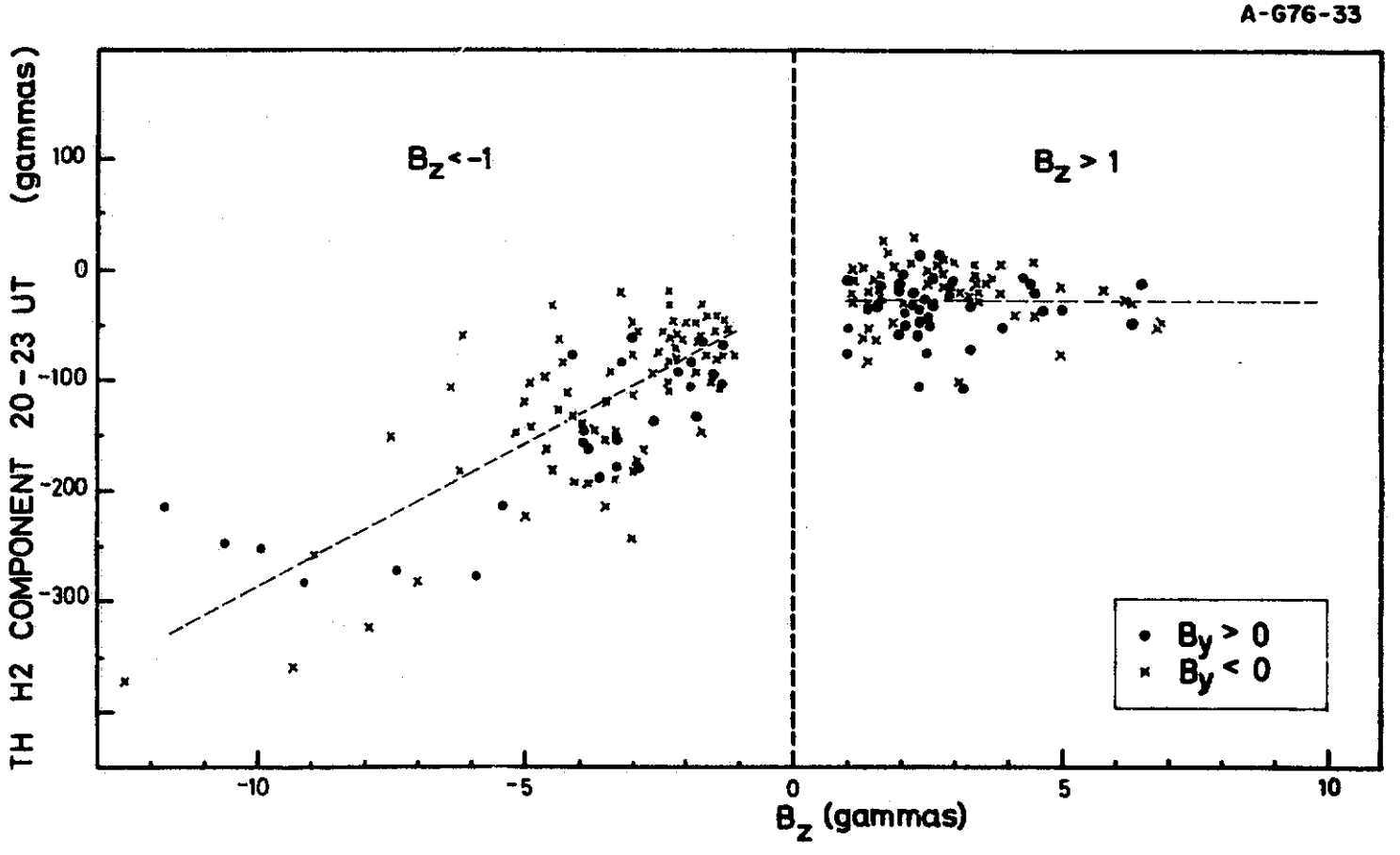
A-G76-33
TH H2 COMPONENT 20-23 UT (gammas)
100
0
-100
-200
-300
B_z<-1
B_z > 1
-10
-5
0
5
10
B_z (gammas)
B_y > 0
B_y < 0

Figure 3

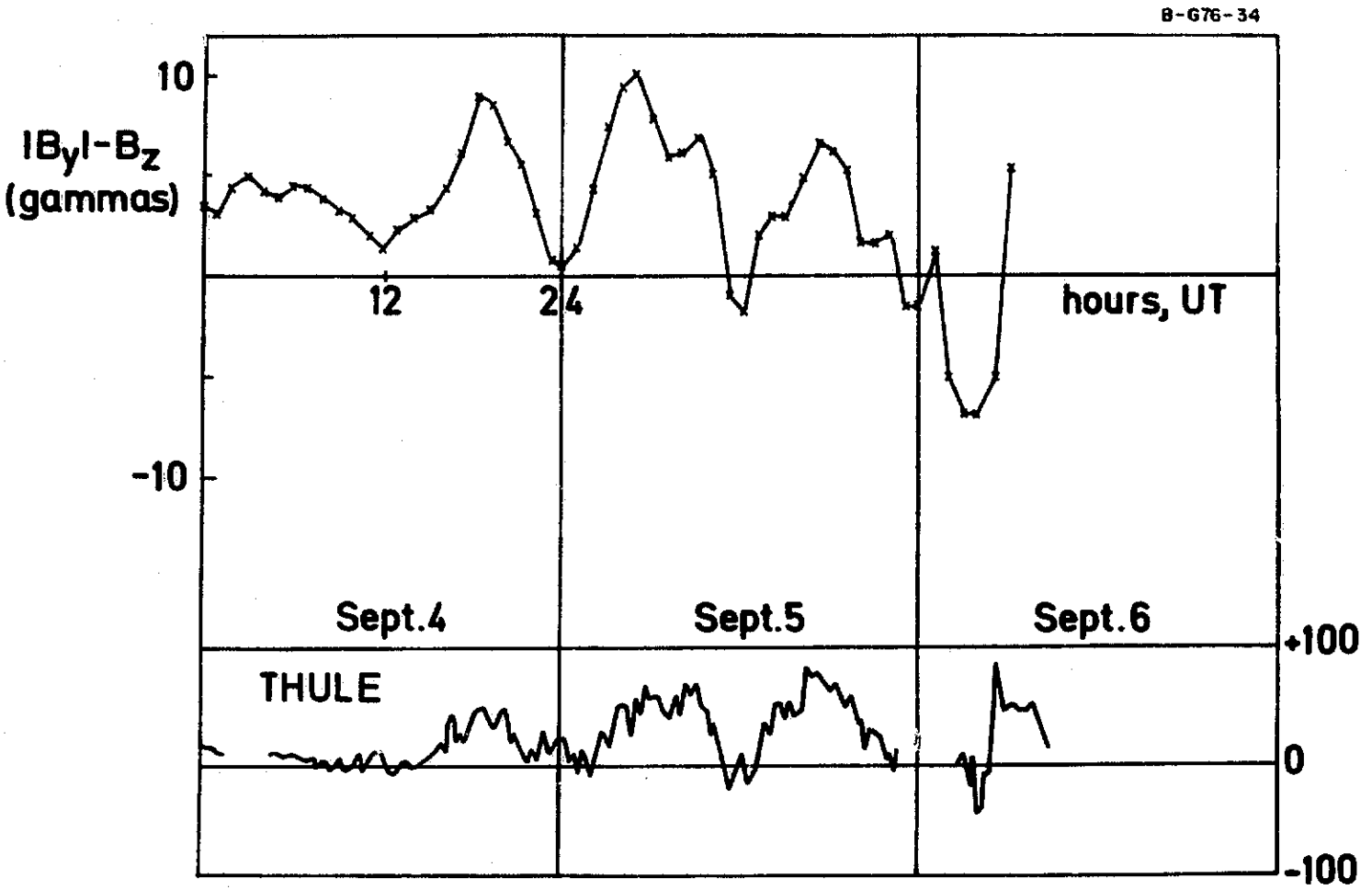
B-G76-34
10
$|B_y|-B_z$
(gammas)
-10
12
24
hours, UT
Sept.4
Sept.5
Sept.6
THULE
+100
0
-100

Figure 4

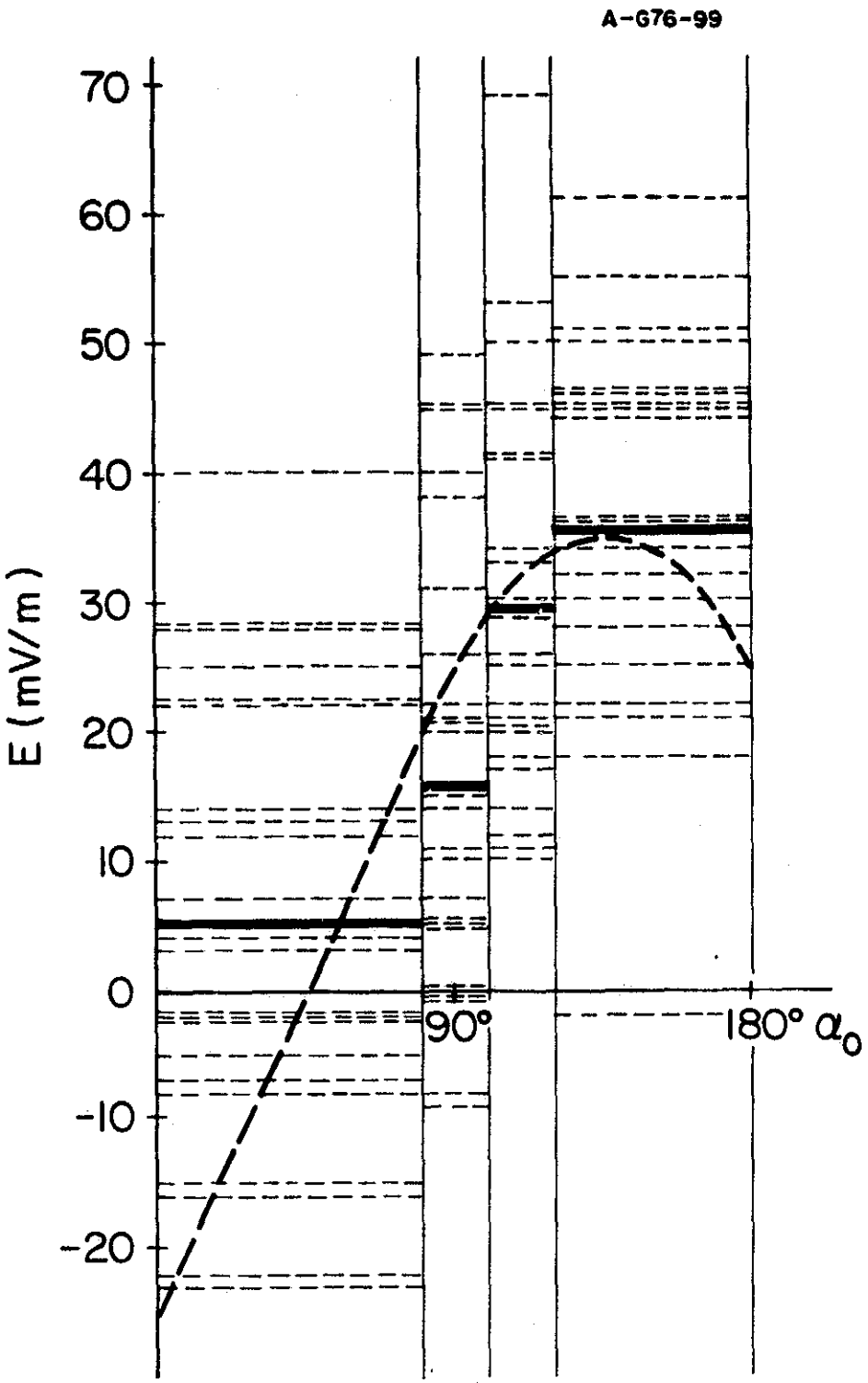

Figure 5

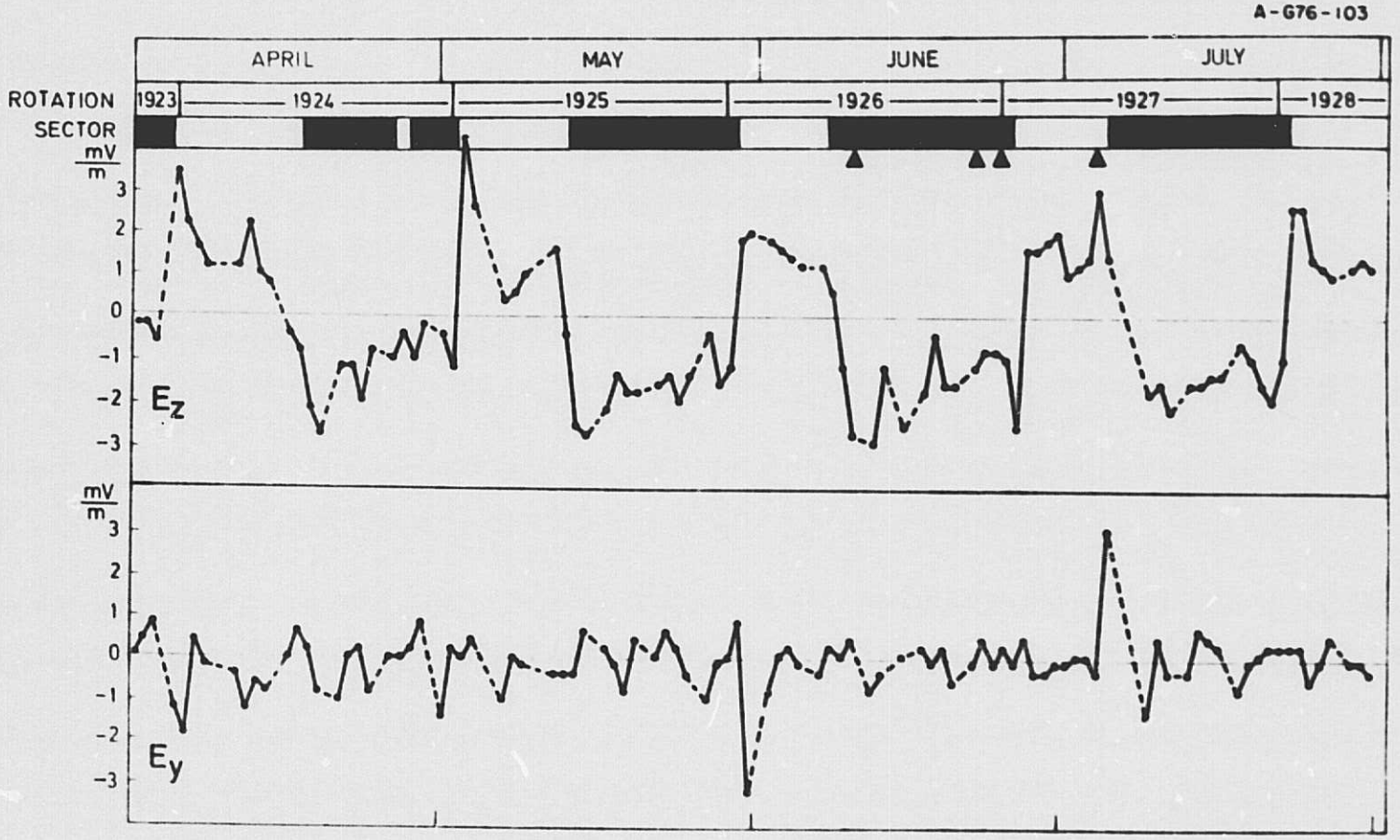
A-G76-103
APRIL
MAY
JUNE
JULY
ROTATION
1923
1924
1925
1926
1927
1928
SECTOR
mV/m
3
2
1
0
-1
-2
-3
E_z
mV/m
3
2
1
0
-1
-2
-3
E_y

Figure 6