Influence of the Transverse Component of the Interplanetary Magnetic Field on the Size of the Auroral Oval

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The auroral boundary index calculated by GUSSENHOVEN *et al.* (1983) on the basis of precipitating electron data is used to examine the response of the auroral oval in the midnight sector to variations of the B_y component of the interplanetary magnetic field (IMF). It is found that the size of the auroral oval with positive B_y is larger (smaller) than that with negative B_y when the earth's dipole tilt angle is negative (positive). This B_y dependence of the auroral oval occurs in the same way in both the northern and southern hemispheres. It is also found that when the magnitude of the transverse component of the IMF is fixed, the largest oval occurs in association with the IMF orientating to $\Theta=11.3$, 0.7 , and -20.5° when the tilt angle of the geomagnetic dipole (T) is in the ranges of $T<-10$, $-10\leq T<10$, and $T\geq 10^\circ$ respectively. Here, Θ indicates the angle measured anticlockwise from the south to the transverse component of the IMF viewed from the sun. The results of data analyses can be explained in terms of the dawnside preference of the dayside magnetic reconnection.

1. Introduction

By examining variations in geomagnetic activity recorded by geomagnetic indices such as the AE index, it has been recognized that solar wind energy is injected into the magnetosphere not only when the interplanetary magnetic field (IMF) points south but when it has other orientations as well. The influence of the B_y component of the IMF on geomagnetic activity and on plasma flow at high latitudes has been reported by many authors (e.g., HEPPNER, 1972; FRIIS-CHRISTENSEN *et al.*, 1972, 1985; PTEMRA and SAFLEKOS, 1979; MATSUSHITA and XU, 1982). In a series of papers, AOKI (1977), HAKAMADA *et al.* (1980), and MURAYAMA *et al.* (1980) showed that the AL index depends negatively (positively) on the IMF B_y when the tilt angle of the earth's dipole axis is positive (negative). Recently, REIFF *et al.* (1981), WYGANT *et al.* (1983), and DOYLE and BURKE (1983) showed that the magnitude of the observed polar cap potential drop can be reproduced by theoretical equations deduced from the reconnection hypothesis. Unfortunately, however, these works do not address the question of the tilt angle dependence of the IMF B_y effect.

Unveiling the quantitative dependence of the IMF B_y on magnetospheric processes will put meaningful constraints on theoretical models of dayside reconec-

tion. MURAYAMA *et al.* (1980) suggested that a more intense westward auroral electrojet flows when the reconnection takes place at the dawnside than at the duskside of the polar cusp. More recently HEELIS (1984) used data of ion convection velocities obtained by *AE-C* to explain the dawnward displacement of the convection "throat", a sunward-antisunward convection reversal zone at the polar cap boundary, in terms of a "preferred" dawnside reconnection (CROOKER *et al.*, 1985). The cause of the dawnside preference, however, is not sufficiently clear at present. Besides, these previous papers are based on observations at northern high latitudes only. Thus there still remains the important question of whether the B_y effect results in a global modulation or a north-south asymmetry of geomagnetic activity.

The size of the auroral oval is one important measure of the relationship between solar wind parameters and geomagnetic activity (HOLZWORTH and MENG, 1975; KAMIDE and WINNINGHAM, 1977; HARDY *et al.*, 1981; NAKAI and KAMIDE, 1983). In particular, the lowest latitudes of the equatorward auroral boundary in each oval expansion correlate very well with the IMF B_z component (PIKE and DANDEKAR, 1979; NAKAI *et al.*, 1986a, b). The purpose of the present paper is to investigate the influence of B_y on the maximum size of the auroral oval by utilizing the auroral boundary index presented by GUSSENHOVEN *et al.* (1982). This paper first investigates whether the northern and southern ovals respond to the IMF B_y in the same sense or in a opposite sense. Second, it examines which component, B_x or B_y , is more important in determining the oval size. In addition, we discuss the possible causes of B_y effects, and the dayside reconnection rate in the light of some of the theoretical predictions.

2. Procedure of Data Analysis

GUSSENHOVEN *et al.* (1982, 1983) utilized DMSP *F2* and *F4* precipitating electron data for 1978 to determine the corrected geomagnetic latitudes of the equatorward boundaries of the auroral ovals in both hemispheres. They prepared a data set containing latitudes of measured boundaries and values of the auroral boundary index derived by mapping the measured boundaries to geomagnetic midnight using statistical formula.

The auroral oval expands generally in association with an increase in the southward component of the IMF, and it contracts as the IMF turns to the north (e.g., KAMIDE and WINNINGHAM, 1977; HARDY *et al.*, 1981; NAKAI and KAMIDE, 1983). By utilizing the auroral boundary index, NAKAI *et al.* (1986a, b) showed that associated with the southward or northward turning of the IMF, the auroral oval expands and contracts with time scales of 45 minutes and 8 hours, respectively. The long time-scales of the oval contraction make correlation coefficients between the oval size and the solar wind parameters rather low. Indeed, the "well expanded" oval is often observed even during periods of the northward IMF (NAKAI and KAMIDE, 1983). On the other hand, since the auroral oval can expand more rapidly than it can contract (PIKE and DANDEKAR, 1979), the equatorward boundary of the auroral oval seems to correlate well with the southward B_z (HARDY *et al.*, 1981). As noted in the

Introduction, PIKE and DANDEKAR (1979) and NAKAI *et al.* (1986a, b) have demonstrated that the lowest latitude of the equatorward boundary highly correlates with the IMF B_z .

Considering the expansion time-scale of 45 minutes, 1 hour running averages of the IMF B_z for 1978 are used. Our data set consists of the negative peaks of the hourly averaged B_z values for which there were auroral boundary index values available within 1 hour. To avoid the possible influences of preceding substorm activity, we have excluded the negative peaks before which a greater southward excursion of the IMF occurred within less than 6 hours. Note also that the present data set does not include data during the period of the northward IMF.

Figure 1 shows variations of the 1 hour running averages of B_z (top panel), the AL index (middle panel), and the auroral boundary index on May 11, 1978 (bottom panel). Solid and open circles in the bottom panel indicate the auroral boundary index derived from measured boundaries in the northern and southern hemispheres, respectively. The minimum peaks of B_z occurred near 0350 UT, 1320 UT, 1700 UT, and 2250 UT. The events at 1320 UT and 2250 UT are not included in our data set because there were smaller B_z within 6 hours before the observations. After the minimum B_z occurred at 0350 UT the DMSP satellite crossed the northern oval at 0407 UT and the southern oval at 0438 UT, when the auroral boundary index values were 54.1 and 53.3 CGL, respectively. The auroral oval contracted slowly until about 1400 UT, and the slightly expanded oval located at 58.9 CGL was observed at about 1746 UT. In association with these two oval expansions, two normal substorms occurred, as one can see in the AL index. However, substorms, except for exceptionally huge one, seem not to significantly influence the oval size (NAKAI *et al.*, 1986b). Therefore in the present paper we do not discuss further on the effect of substorms.

Searching the solar wind parameters and the auroral boundary index for 1978, we found 239 events. To avoid influence from intense magnetic storms, we excluded 36 events for which the transverse component of the IMF (B_t) is greater than 10 nT. Finally, 203 records are available for the following analysis. Among them are 12 events in which values of the auroral boundary index were obtained in both hemispheres within 1 hour of the occurrence time of the corresponding minimum B_z , for example at 0350 UT on May 11, 1978. These pairs of data are regarded as independent of one another.

2.1 Dependence of the auroral boundary index on the IMF B_z

Values of the auroral boundary index (Λ) are plotted as a function of $B_z V$ in Fig. 2, where $V/400$ stands for the solar wind speed normalized by 400 km/s. Solid and open circles indicate the auroral boundary indices observed in the northern and southern hemispheres, respectively. A solid line in the figure indicates a regression line expressed by

$$\Lambda = 65.5 + 1.02 B_z V / 400, \quad (1)$$

Fig. 1. Variations of the 1-hour running average of the IMF B_z (upper panel), the AL index (middle panel), and the auroral boundary index (bottom panel) on May 11, 1978. Solid and open circles indicate the auroral boundary index obtained from observations in the northern and southern hemispheres, respectively.

where the correlation coefficient is 0.76.

2.2 The north-south asymmetry of the auroral oval

Since the magnetic conjugate points shift in association with variations of the tilt angle of the dipole axis, there are possibly differences between the auroral boundary indices obtained at the northern and southern ovals. FAIRFIELD and MEAD (1975)

Fig. 2. The auroral boundary indices obtained within one hour of the occurrence time of the minimum B_z are plotted as a function of the minimum values of $B_z V / 400$. Solid and open circles indicate the auroral boundary index obtained from the ovals in the northern and southern hemispheres, respectively. The solid line indicates a regression line.

showed that when the tilt angle is 30 or -30 degrees and $K_p \geq 3$, a conjugate point in the summer hemisphere with a field line passing through the synchronous orbit at midnight is located about 1° lower in latitude than that in the winter hemisphere. KAMIDE and WINNINGHAM (1977) also found that the equatorward boundaries of the precipitating electrons in the summer hemisphere are located about 1° lower in latitude than those in the winter hemisphere. Figure 3 shows averaged values of $\Lambda - \Lambda_{\text{pred}}$ plotted as a function of the tilt angle, where Λ_{pred} is the invariant latitude predicted from Eq. (1). Solid and open circles indicate the averages in the northern and southern hemispheres, respectively. Data are binned into four ranges, $T < -15$, $-15 \leq T < 0$, $0 \leq T < 15$, and $T \geq 15^\circ$. Bars attached to data points indicate the standard errors. Although the auroral boundary index in the summer hemisphere seems to be located at the lower latitude than those in the winter hemisphere, the differences are less than 1° , and the index is even lower in the winter hemisphere than in the summer hemisphere for the tilt angle range of $0 \leq T < 15^\circ$. The auroral boundary index is derived from the equatorward boundary of the auroral oval in the evening sector (GUSSENHOVEN *et al.*, 1982). Since the latitudinal difference of the magnetic

Fig. 3. Averages of differences between the auroral boundary index (Λ) and the predictions (Λ_{pred}) derived by using Eq. (1) are plotted as a function of the tilt angle of the dipole axis. Solid and open circles indicate the averages in the northern and southern hemispheres, respectively.

conjugate points in the evening sector is supposed to be smaller than those in the midnight sector, it is reasonable that the differences between the northern and southern indices are rather small.

It is also notable in Fig. 3 that when the tilt angle is near 0° the equatorward boundaries of the auroral oval in both hemispheres seem to be located at lower latitudes than are the cases with larger absolute values of the tilt angle. This is consistent with the tilt angle dependence of the AL index (AOKI, 1977; MURAYAMA *et al.*, 1980).

2.3 Relationship between the oval size and the polar cap potential drop

It would be valuable to examine a quantitative relationship between the polar cap potential drop and the auroral boundary index. It is assumed that the polar cap potential drop is expressed by a linear function of the solar wind parameters using two constants, a_0 and a_1 ; i.e.,

$$\Phi = a_0 + a_1 f \quad (2)$$

where f is an arbitrary function of the solar wind parameters. Using our data set, a regression function of the auroral boundary index can be substituted for f in Eq. (2). For example, adopting $E(2)$ of REIFF *et al.* (1981), the polar cap potential drop is expressed by the auroral boundary index in the following form:

$$\Phi = 385 - 4.9 \Lambda. \quad (3)$$

The use of the data set of DOYLE and BURKE (1983) and $B_z V$ as a coupling function gives

$$\Phi = 361 - 4.6 \Lambda. \quad (4)$$

Consequently it is noted that an expansion of the auroral oval by 1° corresponds to an increase in the polar cap potential drop of about 5 kV.

3. Results

3.1 Influences of the B_y component of the IMF

MURAYAMA *et al.* (1980) derived the influences of the IMF B_y on the ratio of the AL index to the solar wind parameters ($AL/(B_s + 0.5)V^2$). In order to compare our results with Murayama *et al.*, we introduce the following function;

$$G = (\Lambda_m - \Lambda) / (\Lambda_m - \Lambda_{\text{pred}}) \quad (5)$$

where Λ_m stands for the values of the auroral boundary index during quiet periods of auroral activity and is set at 69 CGL (MAKITA and MENG, 1984; NAKAI *et al.*, 1986a, b), and Λ_{pred} indicates the prediction of Λ derived by using the Eq. (1). Then the term $(\Lambda_m - \Lambda)$ expresses the increase in the oval size during disturbed periods, and the quantity G expresses the degree of the latitudinal movement of the auroral boundary normalized by that predicted by statistics.

In Figs. 4(a), (b), and (c), G values are plotted as functions of B_y for three different seasons of the tilt angle: $T < -10^\circ$, $-10^\circ \leq T < 10^\circ$, and $T \geq 10^\circ$, respectively. When $T < -10^\circ$, G values with positive B_y is seen to be greater than those with negative B_y , and vice versa when $T \geq -10^\circ$. The solid lines in the figures indicate regression lines. The slopes of B_y are 0.025, 0.000, and -0.035 in Figs. 4(a), (b), and (c), respectively. The slopes of the B_y dependence of the AL index found by MURAYAMA *et al.* (1980) are 0.034 and -0.028 for the tilt angle sections of $T = -28^\circ \sim -21^\circ$ and $21^\circ \sim 28^\circ$, respectively. It should be noted that the B_y dependence of the auroral boundary index is consistent with that of the AL index. Furthermore, the fact that the sensitivity of the auroral boundary index on B_y agrees approximately with that of the AL index implies that the B_y effect on both indices comes from same sources within solar wind/magnetosphere coupling.

Since the interplanetary magnetic field lines generally follow the garden hose line, there is a strong inner correlation between B_x and B_y . To determine which component has a strong influence on the modulation of the auroral boundary index, our data were grouped into four azimuthal sectors distinguished by the signs of B_x and B_y . Figure 5 shows the averaged values of G ($\langle G \rangle$) versus the azimuthal angle of the IMF (ϕ) measured anticlockwise from the antisunward direction viewed from the north. Starting from the top, the three panels show values of $\langle G \rangle$ with a tilt angle of $T < -10^\circ$, $-10^\circ \leq T < 10^\circ$, and $T \geq 10^\circ$. The vertical lines indicate the standard errors. When $T < -10^\circ$, $\langle G \rangle$ in the negative ϕ is greater than unity, while $\langle G \rangle$ in the positive ϕ

Fig. 4. (a) Values of $G = (69^\circ - \Lambda) / (69^\circ - \Lambda_{\text{pred}})$ are plotted as a function of the IMF B_y with the tilt angle of $T < -10^\circ$. Solid and open circles indicate the averages in the northern and southern hemispheres, respectively. The solid line indicates a regression line. (b) Same as (a) except for the auroral boundary index with the tilt angle of $-10^\circ \leq T < 10^\circ$. (c) Same as (a) except for the auroral boundary index with the tilt angle of $T \geq 10^\circ$.

Fig. 4. (continued).

is smaller than unity, and vice versa when $T \geq 10^\circ$. It is significant that no statistical difference is found between the values of $\langle G \rangle$ in $\phi = -90^\circ \sim 90^\circ$ and those in $\phi = 90^\circ \sim 180^\circ$ and $-180^\circ \sim -90^\circ$. Consistent with MURAYAMA *et al.* (1980), this implies that the influence of B_x is much less than that of B_y .

Next, to investigate the question of whether the northern and southern ovals respond to the IMF B_y in the same sense or in an opposite sense, our data were divided into two groups according to whether the data were obtained in the northern or southern hemispheres. In Fig. 6, the values of G averaged in each bin of B_y are plotted as a function of B_y with circles and triangles indicating the averages with a tilt angle of $T \geq 10$ and $T < -10^\circ$, respectively. When $T \geq 10^\circ$, $\langle G \rangle$ values for negative B_y are larger than those for positive B_y for both hemispheres, and vice versa when $T < -10^\circ$. It is evident that the oval size in both hemispheres depends on the IMF B_y in the same sense, implying that variations of the IMF B_y are not subject to north-south asymmetry but to a global modulation of the geomagnetic activity.

3.2 Dependence on the direction of the transverse component

The transverse component of the IMF, which is defined by $B_t^2 = B_y^2 + B_z^2$ is often used in the coupling functions of the solar wind and geomagnetic activity (e.g., PERREAULT and AKASOFU, 1978; KAN and LEE, 1979). Figures 7(a), (b), and (c) show F defined by $F = (\Lambda_m - \Lambda) / (\Lambda_m - \Lambda_{\text{pred}})$ as a function of θ with tilt angles of $T < -10$,

Fig. 5. Averages of $G=(69^\circ-\Lambda)/(69^\circ-\Lambda_{\text{pred}})$ are plotted as a function of azimuthal angle measured from midnight. Bars attached to data points indicate the standard errors. The number of data in each section is shown at the bottom of the panels.

$-10^\circ \leq T < 10^\circ$, and $T \geq 10^\circ$, respectively, where Λ_{pred} indicates a prediction by the regression equation

$$\Lambda = 65.4 - 0.78 B_t V / 400 \quad (6)$$

Fig. 6. Averages of $G=(69^\circ-\Lambda)/(69^\circ-\Lambda_{\text{pred}})$ are plotted as a function of the IMF B_y . Circles and triangles indicate the averages with the tilt angle of $T \geq 10^\circ$ and $T < -10^\circ$, respectively. Solid and open symbols indicate the averages in the northern and southern hemispheres, respectively. Bars attached to each data point indicate the standard errors.

and θ is an angle measured anticlockwise from $-z$ axis to the transverse component of the IMF viewed from the sun. The quantity F indicates the normalized auroral boundary index as same as G but normalized by B_t .

It is evident that the values of F generally decrease as absolute values of θ increase for every section of the tilt angle. However, the axis of symmetry of data points appears to be located at $\theta > 0$ for $T < -10^\circ$, while it appears to be located at $\theta < 0$ for $T \geq 10^\circ$. A quadratic regression analysis provides us with the axes of symmetry for different tilt angles. These are at $\theta = 11.3, 0.7$, and -20.5° for the tilt angle of $T < -10$, $-10 \leq T < 10$, and $T \geq 10^\circ$, respectively. The regression curves are also given by solid lines in the figures. Our simple inspection for the scatter of the points in Figs. 7(a), (b), and (c) indicates that these characteristics are statistically valid. In conclusion, an alternative expression of the B_y dependence can be given in terms of B_t and θ such that when the tilt angle is positive (negative), the largest oval with a fixed value of B_t occurs in association with the IMF orientated westward (eastward) from the south by $10 \sim 20^\circ$.

4. Summary and Discussion

By using the auroral boundary index, the response of the oval size to variations of the transverse component of the IMF has been statistically examined. The "oval size"

(a)

(b)

Fig. 7. (a) Values of $F = (69^\circ - \Lambda) / (69^\circ - \Lambda_{\text{pred}})$ are plotted as a function of θ with the tilt angle of $T < -10^\circ$, where θ is an angle measured anticlockwise from the $-z$ axis to the transverse component of the IMF, viewed from the sun. Solid and open circles indicate the auroral boundary index obtained from the northern and southern hemispheres, respectively. The solid curve shows a quadratic regression line. (b) Same as (a) except for the auroral boundary index with the tilt angle of $-10^\circ \leq T < 10^\circ$. (c) Same as (a) except for the auroral boundary index with the tilt angle of $T \geq 10^\circ$.

Fig. 7. (continued).

in this paper is represented by the latitude of the equatorward boundary of the auroral oval at midnight, which corresponds to the minimum B_z in each southward excursion of the IMF. The obtained results can be summarized as follows:

- (1) The oval size depends primarily on the southward component of the IMF with a correlation coefficient of 0.76, confirming earlier studies.
- (2) The expansion of the auroral oval by 1° in latitude corresponds to an increase in the polar cap potential drop by about 5 kV.
- (3) The size of the auroral oval with positive B_y is larger (smaller) than that with negative B_y , when the earth's dipole tilt angle is negative (positive).
- (4) The IMF B_x component seems to be less important in controlling the oval size than the B_y component.
- (5) The B_y effects occur in the same sense in both the northern and southern hemispheres.
- (6) With a fixed magnitude of the transverse component of the IMF, the largest oval occurs in association with the IMF orientating to $\Theta = 11.3, 0.7$, and -20.5° when the tilt angle is in the ranges of $T < -10$, $-10 \leq T < 10$, and $T \geq 10^\circ$, respectively.

The above results can be discussed in regard to two aspects of the B_y dependence of geomagnetic activity. The first is in terms of the dayside reconnection whose efficiency has been proposed to be controlled by the transverse component of the IMF. Different authors have suggested different formulas for the dayside reconnection using parameters of the magnitude and direction of the transverse component of

the IMF (e.g. SONNERUP, 1974; HILL, 1975; GONZALEZ and MOZER, 1974). However, since none of them properly took into account the effect of the tilt angle, we can not discuss our results by using existing formulas for the reconnection rate. It is interesting to note that HEELIS (1984) and CROOKER *et al.* (1985) suggested that a combination of the so-called antiparallel model and the dawn side preference of the dayside reconnection could explain the influence of the IMF B_y on geomagnetic activity. However, the question of why the magnetic reconnection should occur preferably at the dawn side still remains.

The second consideration is that the B_y dependence relates to changes in the convection pattern in the polar cap. On the basis both of satellite and ground observations, it has been revealed that the polar cap convection changes its pattern considerably in association with B_y variations (RUSSELL, 1972; FRIIS-CHRISTENSEN and WILHJELM, 1975; MCDIARMID *et al.*, 1979; CLAUER *et al.*, 1984; FRIIS-CHRISTENSEN *et al.*, 1985). In particular, it has been reported that when B_y is positive (negative), ionospheric plasma flows downward (duskward) at the "throat" of the antisunward convection in the northern polar cusp region (HEELIS, 1984; BURCH *et al.*, 1985). This implies that geomagnetic field lines reconnected to the IMF with positive (negative) B_y are tugged downward (duskward) in the northern polar cap, and vice versa in the southern polar cap. If this is really the case, the B_y dependence would result in a north-south asymmetry of the geomagnetic activity. This conjecture, however, is inconsistent with the finding in this paper.

The θ dependence of the auroral size, see (6) above, can be explained in the following way to reinforce the dawnside preference of the magnetic reconnection. Figure 8 shows schematically the most preferred region of the dayside reconnection inferred from the present study. Two circles in the figure indicate the dayside

Fig. 8. Schematic views of the magnetopause with positive and negative tilt angles, shown as viewed from the sun. Shaded circles indicate the regions where the magnetic reconnection occurs most effectively. Solid curves with arrows indicate the geomagnetic field lines. Dashed and dotted lines indicate the intersections of the equatorial and ecliptic planes with the magnetopause, respectively.

magnetopause with positive and negative tilt angle viewed from the sun. Solid curves with arrows indicate the geomagnetic field lines. Dashed and dotted lines indicate the intersections of the equatorial and ecliptic plane with the magnetopause, respectively. Since the magnetic reconnection is supposed to depend partially on the magnitude of the sheath field compression in front of the magnetopause, the reconnection usually occurs in the hemisphere where the subsolar point is located. When the tilt angle is positive, the dominant reconnection region is located in the northern hemisphere, since the subsolar point is located in the northern hemisphere. On the other hand, for the negative tilt angle, the dominant reconnection region would be located in the southern hemisphere. Theoretical and numerical studies of the magnetic reconnection suggest that the reconnection rate becomes its maximum when two colliding magnetic fields are antiparallel (e.g., HILL, 1975; HOSHINO and NISHIDA, 1983). Combining (6) in our result and this feature, we infer that the reconnection should take place most effectively on the dawn side rather than around the noon-midnight meridian, as shown by shaded circles in Fig. 8. Although the region where the geomagnetic field is antiparallel to the sheath field extends from the dayside cusp region to the flank of the magnetopause (see LUHMANN *et al.*, 1984), the assumption that the reconnection rate depends partially on the magnitude of the field compression leads to the conclusion that the reconnection generally occurs at low latitudes. Note, however, that this view does not deny the existence of reconnection at high latitudes.

Several hypotheses have been suggested to explain the dawnside preference of the magnetic reconnection. The first follows the observations in which the stagnation point of the solar wind was displaced downward from the subsolar point. However it was shown theoretically by RUSSELL *et al.* (1981) and statistically by CROOKER *et al.* (1984) that such a displacement occurs only when the solar wind Alfvén Mach number is extremely low, i.e., $Ma < 4$ (CROOKER *et al.*, 1985). The second interpretation is that magnetic reconnection will be favored in the region where the vectors of the IMF and of the earth's magnetic field are purely antiparallel (HEELIS, 1984). This indicates that the IMF B_x plays a more important role in the dayside reconnection than does B_y . However, as CROOKER *et al.* (1985) pointed out, this hypothesis contradicts MURAYAMA *et al.* (1980) and (4) above that geomagnetic activity does not depend very much on variations in the IMF B_x (Murayama, private communication, 1986).

These two hypotheses agree with each other on the standpoint that the magnetosheath field configuration in front of the magnetopause is responsible for the dawnside preference. Another possible aspect is to attribute the cause of the dawnside preference to the inside of the magnetosphere. The loss of the magnetic flux tugged away from the front closed region to the tail lobe is compensated for by the return flux from the tail. The dayside magnetopause thereby moves inward or outward following the variation of the reconnection rate and reaches a new equilibrium position as soon as the balance is achieved (CORONITI and KENNEL, 1973). We can speculate that the return flux from the tail will work as positive feedback to control the dayside reconnection rate. Circumstantial evidence for this speculation is found in the observation that at the stagnation point of the dayside magnetopause the strength of the magnetosheath field is proportional to the geometric mean of the stagnation field

strength and the transverse component of the IMF (CROOKER *et al.*, 1982). Ground magnetometer and radar observations indicate that the potential and convection pattern in the northern polar cap are rotated clockwise by $15^\circ \sim 45^\circ$ with respect to the noon-midnight meridian (EVANS *et al.*, 1980; KAMIDE *et al.*, 1981), hence the return flux mapped from the ionospheric sunward convection on the equatorial plane would convect from 2100~2300 MLT to 0900~1100 MLT. Therefore, since the positive feedback from the return current is assumed to be most effective at the dawnside region to the magnetopause, it creates the dawnside preference of the magnetic reconnection. Theoretical or numerical studies on the dayside reconnection model including the return flux from the tail are required in the near future.

Since the oval size is proportional to the polar cap potential drop, values of F shown in Fig. 7 indicate a θ -dependence of the magnitude of the electric field induced by the dayside reconnection. Normalizing at $\theta=0$, values of F averaged in each θ 's bin of 15° are shown in Fig. 9 by solid circles for the tilt angle section from -10° to 10° , where E/E_0 stands for $\langle F \rangle / F(\theta=0)$. Two solid curves show the theoretical predictions by HILL (1975);

Fig. 9. θ dependence of the electric field induced by the dayside magnetic reconnection (E/E_0). Data points are obtained by averaging normalized values of $F=(69^\circ-\Lambda)/(69^\circ-\Lambda_{\text{pred}})$. Bars attached to each data point indicate the standard errors. Solid curves show theoretical predictions derived by using HILL's (1975) equation with $\alpha=1.0$ and 0.6 . The dashed curve is predicted from the half-wave rectifier model.

$$E/E_0 = (\alpha - \cos\theta)^2 / (1 + \alpha^2 - 2\alpha\cos\theta) \quad (7)$$

where $\theta = \pi - |\Theta|$, and α is the ratio of the magnitude of the magnetosheath field to that of the geomagnetic field at both sides of the separator. The two curves are for $\alpha = 1.0$ and 0.6 . The dashed line represents the prediction from the half-wave rectifier model, i.e., $E/E_0 = \cos\Theta$. It is noted that the data points are distributed slightly above the prediction by the half-wave rectifier model (HAKAMADA *et al.*, 1980) and generally agree with HILL (1975) for $\alpha = 0.6$. This confirms the earlier result that Eq. (7) can predict the magnitude of the polar cap potential drop reasonably well (REIFF *et al.*, 1981; WYGANT *et al.*, 1983; DOYLE and BURKE, 1983).

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