Quiet Time Pattern of Auroral Arcs for Different Directions of the Interplanetary Magnetic Field in the Y-Z Plane

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Quiet time arcs observed from the Greenland all-sky camera network have been ordered in corrected geomagnetic latitude/time mass plots according to the values of the $Y$ and $Z$ components of the IMF. Two different patterns of discrete quiet arcs occur. In one system the arcs are ordered along the statistical auroral oval; in the other, which we have called the polar cap pattern of discrete arcs, the arcs are ordered partly in the sun-earth direction over the polar cap, especially on the dawnside of the pole, partly along the 78°-80° corrected geomagnetic latitude curve in the morning to noon and noon to evening hours. The oval arc pattern is most prominent when $B_y$ is negative. It gradually contracts and finally practically vanishes as the steady IMF is shifted toward a northward direction. The contraction takes place differently, depending on the sign of $B_y$. The polar cap pattern is dominant when $B_y$ is positive. The sun-aligned arcs of the polar cap pattern gradually disappear as $B_y$ goes toward negative values. The high-latitude arcs in the forenoon sector seem to be present for all values of $B_y$ considered. No dependence on $B_z$ has been found in the pure polar cap pattern. Apart from periods of extremely great numerical values of $B_y$, the oval and the polar cap discrete arc patterns are found to coexist, at least in our statistical presentation.

INTRODUCTION

The variation through the night of the mean direction of quiet auroral arcs has been studied at single stations by a great number of authors. A survey of some of the results has been given by Hultqvist [1962], who related the orientation of arcs to the corrected geomagnetic coordinate system by showing that the mean orientation during the hours around midnight is at auroral zone stations approximately parallel to the lines of constant corrected geomagnetic latitude. In global studies covering a large interval of magnetic hours, Bond and Thomas [1971] and Akasofu et al. [1972] showed that the arcs tend to lie along the statistical oval. Far inside the auroral oval, arcs have been found to be aligned nearly parallel to the sun-earth direction [Mawson, 1916, 1925; Weill, 1958; Davis, 1960; Denholm and Bond, 1961].

A more detailed study of the direction and position of auroral arcs and bands was reported by Lassen [1973]. On the basis of observations made by all-sky cameras in Greenland he distinguished between different systems of quiet arcs and bands, namely, arcs and bands that are roughly parallel to (and constituting) the nighttime auroral oval, daytime arcs forming the high-latitude dayside part of the oval, and sun-aligned polar cap arcs. The nighttime arcs are closely related to the plasma sheet [Lassen, 1974]. The daytime arcs include the morning [Lassen, 1972] and midday auroras [Akasofu, 1972].

The dependence of the auroral pattern on planetary magnetic activity has been extensively studied since the introduction of the concept of the auroral oval [e.g., Bond and Thomas, 1971; Feldstein and Starkov, 1967; Lassen, 1963, 1970, 1972, 1973]. More recently, observations of a direct relationship between solar wind parameters and the radius of the auroral oval have been reported. The dip of the interplanetary magnetic field (or sign of the vertical component $B_z$ in the solar magnetospheric coordinate system) influences the latitude of the position of the dayside auroral oval [Kaneda, 1971; Pike et al., 1974; Vorobjev et al., 1976] and of the polar cusp electron precipitation [Burch, 1972, 1973; Kivelson et al., 1973; Yashara et al., 1973] as well as of the nightside auroral oval [Akasofu et al., 1973; Akasofu, 1975], a shift from positive to negative $B_z$ giving rise to an equatorward displacement of the auroral oval. A clear correlation between the magnitude of $B_z$ and the radius of the auroral oval, represented by single well-developed arcs, has been demonstrated by Holzworth and Meng [1975]; Berkey et al. [1976] have presented evidence that not only the auroral oval but also the occurrence of sun-aligned arcs over the polar cap is influenced by the sign of $B_y$. In 16 of 18 unambiguous observations of sun-aligned arcs by Isis 2, they found that the interplanetary magnetic field (IMF) was directed northward; for the remaining two observations no IMF data were available. They concluded that this result provides evidence for a strong correlation between the northward direction of the IMF and the occurrence of sun-aligned arcs in the northern polar cap.

The results of Holzworth and Meng [1975] and Berkey et al. [1976] were based on satellite observations of discrete arcs. Ground-based observations of discrete arcs have been performed by the all-sky camera network in Greenland since 1963, resulting in a unique series of observations from the polar cap. We have used these comprehensive data in an attempt to illustrate the dependence of the total pattern of discrete arcs, oval as well as sun-aligned, on the direction of the IMF. In the present report we have used mass plots of auroral arcs in corrected geomagnetic latitude versus time plots to demonstrate first how the quiet time discrete auroral oval contracts when $B_y$ increases from great negative values toward positive values. Next, we examine the contraction of the oval arc pattern with increasing $B_y$ for both positive and negative values of $B_z$ and demonstrate a systematic difference in the way the contraction takes place, according to the sign of $B_y$.

DATA

The auroral data consist of observations from six all-sky camera stations in Greenland, made mainly during the years 1965-1970, supplemented by observations from Ny Ålesund (Spitzberg) for the two seasons 1969-1971. Table 1 gives details about the position of the seven stations as well as the periods for which data from the individual stations have been used. Quarter-hourly mean positions of stable auroral arcs and bands above 10° elevation were determined and plotted in a
corrected geomagnetic latitude–time coordinate system. The data were then ordered into groups representing different values of the IMF. In the analysis a height of the lower border of the forms of 100 km was assumed. Under this assumption, and considering the distribution of the Greenland camera network, the approximate southern limit of observation is at night 63°–64° corrected geomagnetic latitude (CGL). From 0900 hours to 1700 hours corrected geomagnetic time (CGT) the limit is about 70° CGL at midwinter, rapidly increasing in latitude, especially in early afternoon, with increasing separation from the winter solstice. The influence of sunlight is illustrated in Figure 1, which shows the different degrees of coverage of the different parts of the polar graph on December 1. For each station the diagram shows the area corresponding to dark sky (sun’s depression more than 12°). The density of the hatching indicates the degree of overlapping of several stations, thus giving a sort of sensitivity pattern for the camera network. Besides the sensitivity distribution, varying cloud cover as well as failures of camera and satellite recordings of the interplanetary magnetic field influence the observations in unpredictable ways. Hence it has not been regarded as essential for the purpose of our study to have exactly the same observation period at all stations. The attempt has been to include observational intervals from the individual stations long enough to ensure that a reasonable number of arcs become available for the construction of the statistical arc pattern. It is obvious that the graphs produced in the manner described above should not be mistaken for frequency plots. They illustrate the arc pattern exclusively, although a tendency to show a relative frequency distribution of the arcs will no doubt be present in those graphs that contain a great number of observations.

Since it is the aim of the paper to study the distribution of quiet stable arcs, all arcs observed at times when substorm activity was noticeable in the magnetic records at Godhavn, as well as those that showed known auroral postbreakup signatures, were omitted. Thus to a fair degree of certainty the sample represents quiet time substorm-free conditions.

With the aim of ordering the data, hourly mean values of the interplanetary magnetic field [King, 1975] corresponding to the time of observation of arcs have been transformed into solar magnetospheric coordinates. Since a time delay, the magnitude of which depends on the position of the satellite, is expected between the satellite observation and the corresponding effect in the ionosphere, the study has been confined to steady state conditions by demanding that the sign of the mean value of each component of B be equal to the sign during the hour prior to the observational hour. All observations of auroral arcs and bands, selected as described above and occurring during hours with steady IMF components, were ordered with respect to the magnitudes of $B_x$ and $B_z$, the average of the hourly mean values of the azimuthal and vertical components of the IMF for the actual and the preceding hour.

**VARIATION OF THE ARC PATTERN WITH $B_z$**

Mass plots of the arcs in corrected geomagnetic latitude versus time diagrams are presented in Figure 2 for nine intervals of $B_z$ as indicated below each diagram.

For the largest negative values of $B_z (B_z < -6.9 \text{ nT})$ the arcs are seen to be ordered in a belt (the discrete auroral oval), the polar border of which is nearly circular with a radius of 17°–18°. The center is shifted from the pole to 88° CGL at 2100 hours CGT, introducing an obvious asymmetry between morning and evening. The area poleward of this border is practically void of discrete auroras. The equatorward border of the oval is less well defined. It may be outside the field of view of the southernmost station (i.e., equatorward of about 63° CGL), at least in the midnight sector. The width of the oval in the plot is probably in part determined by the difference in time lag for the individual arcs between the negative turn of $B_z$ and the observation of the arc [Akasofu, 1975].

A group of arcs parallel to the latitude circles at 78°–80° in

### Table 1. Stations From Which Data Are Used

<table>
<thead>
<tr>
<th>Station</th>
<th>Geographical Latitudes, °N</th>
<th>Geographical Longitude, deg</th>
<th>Corrected Geomagnetic Latitude, °</th>
<th>Midnight</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thule</td>
<td>77.5</td>
<td>290.8</td>
<td>86.8</td>
<td>0200</td>
<td>1965-1971</td>
</tr>
<tr>
<td>Nord</td>
<td>81.6</td>
<td>343.4</td>
<td>80.4</td>
<td>0200</td>
<td>1963-1972</td>
</tr>
<tr>
<td>Ny Ålesund</td>
<td>78.9</td>
<td>11.9</td>
<td>75.6</td>
<td>2100</td>
<td>1969-1971</td>
</tr>
<tr>
<td>Sánder Stræmfjord</td>
<td>67.0</td>
<td>309.2</td>
<td>75.4</td>
<td>0200</td>
<td>1965-1967, 1967-1970 for $K_p &gt; 4$</td>
</tr>
<tr>
<td>Kap Tobin</td>
<td>70.5</td>
<td>338.0</td>
<td>72.7</td>
<td>2330</td>
<td>1965-1967, 1967-1970 for $K_p &gt; 4$</td>
</tr>
<tr>
<td>Narssassuaq</td>
<td>61.2</td>
<td>314.6</td>
<td>68.8</td>
<td>0200</td>
<td>1965-1967, 1967-1970 for $K_p &gt; 4$</td>
</tr>
</tbody>
</table>

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**Fig. 1.** Sensitivity pattern for the camera network, showing the total area in corrected geomagnetic coordinates, in which observation is possible at a solar depression angle greater than 12° from at least one station. Increasing density of hatching indicates simultaneous coverage by an increasing number of stations. The pattern is valid for the solar declination on December 1.
Fig. 2. Mass plots of arcs in corrected geomagnetic coordinates for different values of $B_z$.

The dawn to noon sector and directed toward the early morning oval appears in the $-7.0 < B_z < -4.9 \text{ nT}$ plot and remains in approximately this position for all higher values of $B_z$. This group has been called the morning auroras [Lassen, 1972]. The morning auroras have been found to be visible near 77° CGL for all levels of magnetic activity except the highest values of $Kp$, for which they are displaced several degrees equatorward [Lassen, 1963, 1972]. With this background a possible interpretation of the asymmetry in the $B_z < -6.9 \text{ nT}$ plot is that the asymmetric oval is composed by a symmetric oval from dusk to dawn overlapped by a group of morning auroras displaced $\sim 5^\circ$ equatorward from their quiet time position between noon and $\sim 0300$ hours MLT. Some low-latitude arcs at $\sim 2000$ hours CGT ($-1.0 < B_z < +1.0 \text{ nT}$ and $+0.9 < B_z < +3.0 \text{ nT}$) may correspond to a value of $B_z$ which is lower than the bihourly mean value used by us. The table [King, 1975] gives hourly averages only; a transition to negative $B_z$ in the later part of the hour may explain the position of some arcs equatorward of the main bulk of arcs corresponding to the mean value of $B_z$ used here.

For $B_z > 3 \text{ nT}$ it becomes more and more difficult to maintain the conception of a discrete auroral oval. Arcs of the oval pattern are observed sporadically only; the greater part of the pattern is missing or below the sensitivity threshold of the
cameras. A group of arcs situated at 80° in the afternoon and observed for all positive values of $B_z$ may be part of a contracted oval, or they may represent a high-latitude occurrence in the afternoon which is analogous to the morning auroras. The limitation of our observation techniques, demonstrated in Figure 1, does not allow us to state whether these arcs belong to the discrete arc oval or form a special inner group. All we can say is that they appear to be situated at the inner edge of the discrete oval.

Sun-aligned arcs begin to appear over the polar cap in the diagrams representing $-5.0 < B_z < -2.9$ nT. They become increasingly important, especially on the dawnside of the polar cap as $B_z$ trends toward greater positive values. There is a maximal concentration of arcs between 82° and 88° at dawn, but the distinction between sun-aligned polar cap arcs and oval-aligned morning auroras, concentrated at 78°-80°, may be difficult.

For large positive values of $B_z$, when the discrete arc oval is practically dissolved, the arc pattern shows some semblance to a two-cell pattern. It has not been possible to state whether the arcs in the night area of the oval are remainders of the population of oval arcs or whether they relate to the population of sun-aligned arcs. Observations of a discrete connection between sun-aligned and oval-aligned arcs tend to support the latter assumption. We call this residual high-latitude pattern the polar cap arc pattern.

The net result of the diagrams shown in Figure 2 seems to be that two different patterns of quiet arcs exist. When the IMF is
directed extremely southward, the arcs are ordered along the auroral oval. This pattern gradually contracts and finally becomes dissolved as the steady IMF is shifted toward a northward direction.

When the IMF is directed extremely northward, the pattern is formed by sun-aligned arcs across the polar cap, which show a tendency to be more frequent in the day half with a maximum ridge between 82° and 88° CGL at 0600 hours CGT, and a system of arcs near and parallel to 80° CGL on the dayside from dawn to dusk. The sun-aligned arcs and the morning arcs meet in an acute angle at 80°-82° CGL and 0800-1100 hours CGT. As the steady IMF shifts toward a southward direction, this pattern gradually becomes dissolved. Only the morning arcs at 78°-80° appear to be observable at all Bz values except the lowest represented here.

The two patterns corresponding to northward and southward IMF appear to coexist when Bz is near zero.

**Variation of the Arc Pattern With Bz**

In Figure 3 the arcs have been grouped with reference to the values of both Bz and By. The upper row of the figure shows the arc pattern for positive Bz (Bz ≥ 3 nT), one plot for each of the groups Bz negative (Bz ≤ −1.5 nT), Bz ~ 0 (−1.5 nT < Bz < 1.5 nT), and Bz positive (Bz ≥ +1.5 nT). The second row shows the corresponding plots for By negative (By ≥ 0.5 nT), and By positive (By < +1.5 nT). The two patterns shown in the diagrams for By negative and the lower row for negative B (B < −1 nT) are the corresponding development, but in this case the contraction of the oval does not take place in a symmetrical way. The position of the equatorial boundary at dawn is almost independent of Bz, whereas concurrently the arc distribution broadens and approaches the pole. Consequently, in the graph for Bz positive the polar cap pattern is supplemented by arcs which appear to constitute an oval, the morning branch of which passes from ~70° at midnight through 72°-74° at dawn and, apparently, along the equatorial border of the 80° morning auroras. The evening branch is formed by a broad area of sun-aligned arcs, which are curving poleward on their western ends in the premidnight hours and traversing the eveningside of the polar cap between ~77° and 86°. For negative Bz, arcs in the dawn sector move poleward and expand to fill the gap between high-latitude morning auroras and sun-aligned polar cap auroras as Bz trends negative to positive. Although the dominant feature in the dusk sector is a dissolution and disappearance of the oval pattern, arcs in the original (Bz negative) position of the oval are present in the midnight hours even in the graph for Bz positive. These arcs tend to be directed toward latitudes lower than 80° at dusk. It should be noticed that the upper row of Figure 3 represents the arc pattern for values of Bz greater than 3 nT. For still greater positive values of Bz, the oval system disappears (cf. Figure 2). In this case no significant dependence on By has been observed in the polar cap pattern. The conclusion drawn from the diagrams shown in Figure 3 is that the contracted oval (Bz positive) is influenced by Bz. When Bz is positive, the oval is shifted toward dawn, whereas a shift toward dusk may be inferred from the diagrams for Bz negative.

The influence of Bz on the oval pattern is not restricted to the position of the contracted oval. Thus although the oval configuration in Figure 3 for Bz negative is at first glance nearly similar for the different signs of Bz, a closer inspection reveals that at 2200-0600 hours CGT the equatorward border of the discrete arc oval for positive Bz is situated 27°-4° poleward of the corresponding border for negative Bz. Also, the arcs in the evening-midnight sector are less regular than those for Bz negative: in the 2000-2200 hours sector at 72°-76° the arcs apparently contain loops (westward-traveling surges) and other features mainly from small substorms that our selection methods failed to reject from the data set. For Bz negative the difference could be fortuitous. However, it is in agreement with this assumption. Thus the difference between the Bz positive and the Bz negative patterns for negative Bz may indicate that substorms are more frequent when Bz is positive. This observation has its counterpart in magnetic observations. Friis-Christensen and Wilhelmsen [1975] have shown that the average westward auroral electrojet is in winter more intense for positive than for negative Bz. Aoki [1977] extended the result by showing that during winter months the average value of the auroral electrojet index AL is numerically greater for positive Bz.

**Occurrence Frequency and Field Orientation**

As was pointed out in a previous section, the polar graphs in Figures 2 and 3 illustrate the arc patterns rather than the distribution of frequency of occurrence of arcs. Thus a comparison of the individual graphs will not in general give reliable information about the behavior of the frequency (or intensity) of the auroras as a function of the magnitude of the components of the IMF.

One exception to this statement may possibly be present in the lower row (Bz negative) of Figure 3. Here an obvious difference between the plots for positive and negative Bz is the abundance of arcs in the afternoon oval pattern for positive Bz compared with the lack of arcs in the same sector for Bz negative. The difference could be fortuitous. However, it is in agreement with an (unpublished) result which we have found some years ago in connection with a study of the occurrence frequency of auroras (any form) at Nord. For the southern part of the sky (76°-79°) the diurnal frequency of occurrence was found to have its main maximum at 1200-1600 hours CGT. The magnitude of this maximum was found to be independent of the planetary magnetic activity index Kp on A days (Kp away from the sun, i.e., Bz in general positive [Svalgaard, 1972]), whereas on C days (Kp toward the sun, Bz negative) there was a rapid decrease of the magnitude with increasing Kp. Substituting Bz for Kp (which may be done in qualitative comparisons), the result is in agreement with Figure 3. The explanation of this observation is not known at present. Apparently, the oval pattern may be situated more equatorward (in daylight) in the Bz negative afternoon sector, or the arcs in this sector may be less intense (i.e., less frequently above the threshold of visibility) or absent when Bz is negative. A corresponding dependence on Bz of the frequency of occurrence of arcs of the polar cap pattern is suggested by visual observations. As is apparent from Figure 2, sun-aligned polar cap arcs are occasionally observed from Godhavn (77° CGL) in the midnight hours. During the five winters of 1951—
1956, visual observations of auroras were made every clear evening [Lassen, 1963]. From this series all observations of quiet sun-aligned arcs made during the interval 2030-0330 hours CGT were grouped according to the inferred IMF polarity [Steinberg, 1972]. Of 34 evenings with sun-aligned arcs, 27 occurred in 'away' sectors, 6 in 'toward' sectors; in one case the field polarity was uncertain. However, the months of observation contain a total of 333 away and 207 toward sector evenings in toward sectors.

The diagrams in Figure 3 do not demonstrate a corresponding difference in number of sun-aligned polar cap arcs in the midnight area dependent on $B_y$. However, as was pointed out earlier in this paper, the diagrams should not be considered as frequency plots. Therefore, in spite of the absence of a $B_y$ dependence in the plots, we conclude that the (nightside of the) polar cap pattern is most frequently observed when the IMF is directed away from the sun. This result was suggested by Yeager and Frank [1976] from an investigation of intensities of low-energy electrons in the distant polar magnetosphere.

**Discussion**

The main result of our study is a model consisting of two different patterns of quiet auroral arcs. It is well known that the discrete arc oval pattern is accompanied by continuous (diffuse) aurora. The complete auroral oval corresponds to and is more or less identical with similar patterns in other geophysical parameters such as particle precipitation, field-aligned currents, and plasma convection (electric fields and Hall currents). Therefore it is to be expected that some of our findings have their parallels in the behavior of the oval patterns for these other quantities. Also, it is possible that the polar cap arc pattern may manifest itself in the distribution of other quantities, when $B_y$ is positive. In the following we compare our results with relevant observations of the above-mentioned parameters.

**Particle Precipitation Measurements**

Measurements of energy spectra and fluxes for electrons causing the sun-aligned arcs over the polar cap [Romick and Brown, 1971; Whalen et al., 1971; Meng and Akasofu, 1976] suggest electron spectra that peak between 1 and 2 keV, with a peak intensity for a 1-kR arc of ~$10^7$ cm$^{-2}$s$^{-1}$ keV$^{-1}$. The arcs are observed on a background of low-energy electrons (few hundred electron volts). Heikkila [1972] and Winningham and Heikkila [1974] reported isolated regions of enhanced structured electron fluxes with energies below 1 keV, observed on polar cap passes of Isis 1. They regarded these 'showers' as the cause of the sun-aligned arcs typical for the quiet-time polar cap [Heikkila, 1972]. Winningham and Heikkila drew attention to a characteristic difference in the structure of the showers: on the dawnside they are of very limited extent, corresponding to a spatial structure of a few kilometers, but on the duskside of the noon-midnight meridian the enhancements are spatially broader (up to 300 km), and the electron spectra are somewhat harder. This statement was illustrated by the record from the traverse of the northern polar cap on orbit 966, reproduced by the authors as Figure 5 [Winningham and Heikkila, 1974]. The traverse took place on a QQ day with $Kp = 1$, in an away sector [Mansurov et al., 1976]. The position of the showers on this orbit fits well into the $B_y$ positive, $-0.1 \text{ nT} < B_z < +3.0 \text{ nT}$ diagram of Figure 3, showers of limited extent corresponding to arcs in the dawn sector, while the broader ones are located in the area which we have regarded as the broadened, contracted dusk sector of the oval pattern. Thus our distinction between the two groups of sun-aligned arcs appears to be supported by particle measurements.

We conclude that our plots of quiet auroral arcs indicate the distribution of precipitation of ~1 keV electrons over the polar cap during periods of low activity ($B_z$ positive). The complete distribution of precipitating electrons is believed to be found by adding to the discrete sun-aligned arcs an area of soft background emission, in which the arcs are (at least in some very quiet situations) found to be embedded [Romick and Brown, 1971; Foster and Burrows, 1976].

**Field-Aligned Currents**

Observations of field-aligned currents from three-axis magnetic measurements on the Triad satellite have revealed the existence of large-scale field-aligned currents, concentrated in two principal areas encompassing the geomagnetic pole [Ujima and Potemra, 1976]. On the morningside of the earth, currents flow into the ionosphere at high latitudes and out at lower latitudes, while on the afternoonside the situation is reversed. The currents are located in the area of the instantaneous auroral oval, the discrete auroral evening arcs being in general situated within the latitude regime occupied by the upward field-aligned current and the diffuse aurora located equatorward of discrete auroras corresponding to the region of downward field-aligned current [Armstrong et al., 1975; Kamide and Akasofu, 1976].

Recently, McDiarmid et al. [1977] reported the existence in the dawn sector of field-aligned currents at high latitudes, directed oppositely to the usual pattern. This reversed current pattern was observed in a few percent of the dawn-dusk passes of the Isis 2 satellite. In all, seven such cases were found in which the magnetic disturbance values were significantly above the noise level; all occurred on the morningside of the earth. There were, in addition, a few afternoonside cases which may be similar but where the disturbance values are close to the noise level. In all cases of reversed current pattern the IMF had a strong northerly component. However, not all times of strong northerly IMF corresponded to reverse current patterns; in fact, in more than half such cases examined, the field perturbation, if it occurred, corresponded to the normal pattern. The authors point out that besides the northerly IMF one more condition must apparently be fulfilled for the reversed current pattern to occur. The information about the seven successful passes given by the authors has allowed us to compute the values of $B_y$ at the time of the observations. It appears that $B_y$ is positive in six of the seven cases. In one case the 2-hour average is negative, but the sign changes several times during the period, and for one of the hours IMF observations are only available during two 10-min intervals. This fact may suggest that the second condition mentioned above is that $B_y$ should be positive. We have compared the reported position of the reversed current system with our $B_y$ positive, $B_z$ positive plot of Figure 3. In Figure 4 we have plotted the position of the currents, based on Figure 5 of McDiarmid et al. Except for the two traverses shown in their Figures 3 and 4, information is available only at the endpoints of the total current pattern, wherefore the midpart of the traverse has been left open in our figure. The position of the reversed current pattern in Figure 4 appears to fit the polar cap discrete arc pattern in the sense that the area of downward current roughly coincides with the group of 78°-80° morning arcs; the area of upward current is situated in the dawnside of the polar cap between the morning
arcs and the maximum concentration of sun-aligned polar cap arcs. Fluxes of precipitating electrons ($E \leq 150$ eV) were present in the region of the upward currents [McDiarmid et al., 1977], in agreement with the expectation of a faint background radiation in this area. Also, spikes of 1.3-keV electrons $\sim 10^9$ cm$^{-2}$ s$^{-1}$ sr$^{-1}$ keV$^{-1}$, suggesting auroral arcs, can be seen in the region of upward currents [McDiarmid et al., 1977, Figure 4]. These observations indicate that the reversed field-aligned currents are related to the polar cap arc system in analogy to the relation between field-aligned currents at lower latitude and the evening auroral oval.

**Plasma Convection**

On the basis of observations of electric fields made on the Ogo 6 satellite, Heppner [1972] found that the latitude of the boundary between the oval convection pattern and the polar cap is dependent on the sign of $B_y$. When $B_y$ is negative, the boundary is shifted $2^\circ$-$5^\circ$ toward the pole from its average position at dawn; when $B_y$ is positive, a similar shift toward the pole is observed at dusk. Our observations show a corresponding shift along the dawn-dusk line of the oval distribution with $B_y$ (cf. the discussion of Figure 3), but the effect is only apparent in the distribution of discrete auroral arcs when $B_y$ is positive.

**SUMMARY OF OBSERVATIONS**

The observations reported here have led us to the following conclusions:

Two different patterns of discrete quiet arcs occur. In one system the arcs are ordered along the statistical auroral oval; in the other, which we have called the polar cap pattern of discrete arcs, the arcs are ordered partly in the sun-earth direction over the polar cap, especially on the dawnside of the pole, and partly along the $78^\circ$-$80^\circ$ latitude curve in the morning to noon and noon to evening hours.

The oval pattern is most prominent when $B_y$ is negative. It gradually contracts and finally becomes dissolved as the steady IMF shifts toward a northward direction. The contraction takes place differently, depending on the sign of $B_y$. For $B_y$ positive the contraction takes place essentially in the evening sector of the oval. While gradually broadening, it moves toward higher latitude, whereas the position of the oval in the morning sector remains nearly unchanged. For $B_y$ negative the oval in the morning sector, while gradually broadening, moves toward higher latitude, whereas in the evening sector the oval undergoes a slight contraction and fades away. Even for highly negative $B_y$ values, the oval pattern is found to be dependent on $B_y$, the equatorward boundary being in this case from midnight to dawn several degrees lower in latitude for negative than for positive $B_y$.

The sun-aligned arcs of the polar cap pattern gradually disappear as $B_y$ trends toward negative values. The high-latitude arcs in the forenoon sector seem to be present for all values of $B_y$ considered, except the lowest ones. No significant dependence of the polar cap pattern on $B_y$ has been found in our data, but the frequency of occurrence (intensity) of the sun-aligned arcs appears to be greater for positive than for negative $B_y$.

Apart from periods of extremely great numerical values of $B_y$, the oval and the polar cap discrete arc patterns are found to coexist, at least statistically.

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**REFERENCES**


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