Seasonal Variations of Field-Aligned Currents

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Field-Aligned Currents の季節変化

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要旨: TRIAD 衛星により，北半球高緯度地方で観測された磁場データを解析して，沿磁力線電流 (FAC) の季節変化を調べ，以下の結果を得た．

1) 昼間部分では FAC 強度は，季節と共に変動する．夏の FAC 強度は，冬のそれと比べて約2倍大きい．それに対し，夜間部分では FAC の季節変化は，ほとんど見られない．

2) 夏の単層構造の FAC の強度期待値は，冬のそれと比べて十分大であるが，2重層構造については，季節変化はあまり見られない．また，単層構造の FAC の最大強度領域は冬になると夏に比べて昼間領域に近づく．

3) 単層および 2 重層構造両方の FAC を考慮に入れると，電離層に入り込む FAC の総量は，出る FAC の総量に 10% の誤差の範囲で等しい．

4) 季節変化を取り除いたのちには，地磁気活動度に対する FAC の依存性が見られる．地磁気活動度が増加すれば，FAC 強度も増加する．$Kp \leq 2$ から $2 < Kp \leq 4$ に変わる時の FAC 総量の増加は，冬から夏に変わった時の各地磁気活動度での FAC 総量の増加より大であるが，各 2 MLT での季節変化の効果を無視することはできない．

5) FAC の位置の季節変化は，昼間部分で著しく見られた．夏の FAC の緯度は，冬のそれに比べて高い．

6) 昼間の FAC 分布構造は複雑であるが，統計的には折れまがりの見られることもあった．

Abstract: From magnetometer data obtained by TRIAD in the northern high latitudes, seasonal variations of field-aligned currents (FAC) are investigated.

1) In the dayside region intensities of FAC's vary with seasons. The intensity of FAC amplitude in summer is about twice as large as that in winter. On the contrary there are no seasonal variations of FAC's in the nightside region

2) Expected value of single structured FAC in summer is much greater than that in winter whereas expected value of double structured one in summer is nearly comparable to that in winter The maximum intensity region of single structured FAC in winter is located at more dayside region than that in summer.

3) From the analysis of the data observed at the northern high latitudes, each

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type of FAC (single and double structured) is balanced by itself within the error of 10%

4) After separating the effect of seasonal variations of FAC's there remains the dependence of FAC upon geomagnetic activity. With geomagnetic activity increasing, FAC intensity increases. The contribution of seasonal variations to total current input and output is less than that of geomagnetic activity variation from $Kp \leq 2$ to $2 < Kp \leq 4$ However, the contribution of seasonal variation to FAC's for each 2-hour MLT segment cannot be neglected.

5) FAC location varies with seasons especially in the dayside region Location in summer is higher than that in winter in the dayside region.

6) The distribution of FAC in the midday region was statistically found to exhibit a kink

1. Introduction

Field-aligned currents (FAC) play an important role on solar wind-magnetosphere interaction, magnetosphere-ionosphere coupling, and dynamics in the magnetosphere During the past several years, characteristics of the FAC have been studied from various kinds of aspects. An overall and detailed review of FAC was done by KAMIDE (1979). In this paper, we review the FAC briefly. Global morphology of FAC and its dependence on magnetospheric activity have been researched by analyses of magnetic field variations observed on spacecrafts (ZMUDA and ARMSTRONG, 1974; SUGIURA, 1975; SUGIURA and POTEMRA, 1976; IIJIMA and POTEMRA, 1976a, b; IIJIMA and POTEMRA, 1978; IIJIMA *et al.*, 1978). Relationship between the FAC and associated phenomena have also been studied by several authors; large scale structured particle precipitation and the FAC by spacecraft observations (POTEMRA *et al.*, 1977; MCDIARMID *et al*, 1978), small scale structured one and the FAC by rocket observations (CLOUTIER *et al.*, 1973; ARNOLDY and CHOY, 1973; CASSERLY, 1977), visual aurora phenomena and the FAC (KAMIDE and AKASOFU, 1976; KAMIDE and ROSTOKER, 1977, KAMIDE *et al.*, 1979), and equivalent current system (ground magnetic field observations) and the FAC (KAMIDE *et al.*, 1976; BAUMJOHANN *et al.*, 1979). Even now some essential problems, namely, original sources which drive the FAC and entire closure of the FAC between the magnetosphere and the ionosphere are not definitely known yet. In order to solve these problems, following two analyses are useful. One is to investigate how the ionosphere controls the FAC. Ionospheric electrical conductivity has a variation in season, especially in the dayside region, because a zenith angle of the solar EUV that ionized upper atmosphere varies with seasons (BREKKE *et al.*, 1974, VAN'YAN and OSIPOVA, 1975). In order to investigate the magnetosphere-ionosphere coupling we need to know how this variations of the electrical conductivity and deformation of the magnetosphere control FAC intensity and location. Next is to investigate a balance of the FAC's on the ionosphere. The variations of FAC's are attributed to regional variations (magnetic local time (MLT) and invariant latitude (INV)), magnetospheric activities, and seasonal variations. If we know seasonal variations of the FAC's, we can separate the seasonal variations from several kinds of FAC variations. Then we can precisely estimate three-dimensional current balance on the ionosphere and dependence upon magnetospheric activity. This procedure gives us a hint to know how sources of FAC's connect with each other in the magnetosphere and the ionosphere and how the activity of the magnetosphere affects the FAC's.

In this paper, we studied the seasonal variations of FAC's in order to investigate the problems above mentioned. As mentioned before, several magnetospheric and ionospheric phenomena relate to the FAC's and most of them vary with seasons: equivalent current system observed at ground stations (FRIIS-CHRISTENSEN and WILHJELM, 1975; NAGAI and FUKUSHIMA, 1979), particle precipitation (BERKO and HOFFMAN, 1974), electric field (KAMIDE, 1979; private communication), and plasma wave phenomena (MAKITA and FUKUNISHI, 1973; JAMES, 1976). However, the seasonal variations of the FAC's have been studied only once by data obtained by TRIAD (SUGIURA and POTEMRA, 1978). They found that intensity of the single-sheet structured FAC in summer is much larger than that in winter. Up to date, however, no one knows where the seasonal variations of FAC's are remarkable and how the balance of FAC is in one hemisphere. In later section, the seasonal variations of FAC intensity, those of FAC location, dependence of FAC upon magnetospheric activity, and current balance of FAC's in the northern hemisphere are analyzed and discussed.

2. Data

We utilized TRIAD satellite data received at Resolute Bay (geomagnetic latitude 83°, geomagnetic longitude 287°) in 1976, 1977 and at College (64.7°, 256°) in 1973 and 1974. The location of these stations are displayed in Fig. 1. TRIAD satellite is polar orbital encircling the Earth at the altitude of about 800 km. It has a three-component fluxgate magnetometers observing magnetic field components with a resolution of 12 nT. Detailed description of instrumental and orbital informations were given by ZMUDA and ARMSTRONG (1974). The data received at Resolute has an advantage to make it possible to analyze the characteristics of FAC during wider magnetic local time (MLT) interval in each season than the data received at College, because Resolute is located at higher geomagnetic latitude than College. By using the data obtained at these stations, we could cover whole MLT in each season. About 1000 passes of TRIAD data were subjected to the present analysis. Number of data sampled in each 2-hour MLT segment are shown in Fig. 2. As already known (FUJII and IIJIMA, 1979),

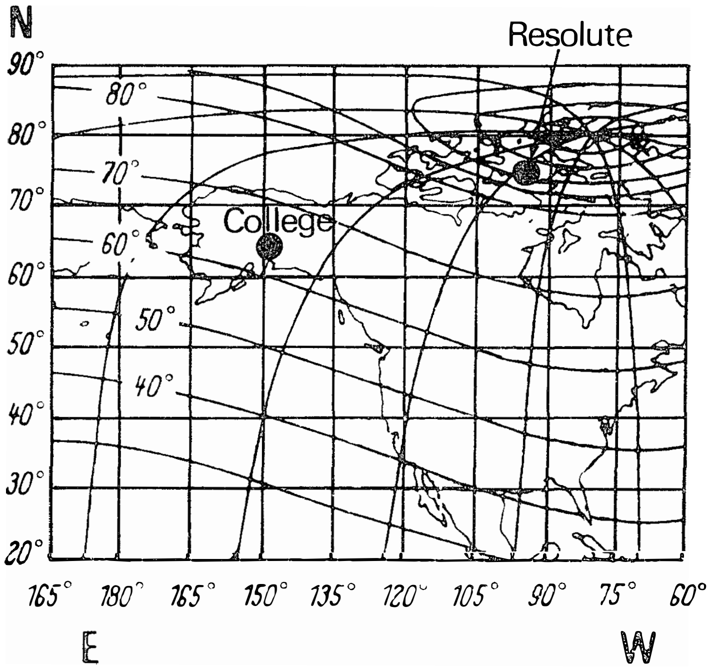


Fig 1 The locations of TRIAD tracking stations, Resolute and College Magnetic field data are obtained at these stations on real time telemetry

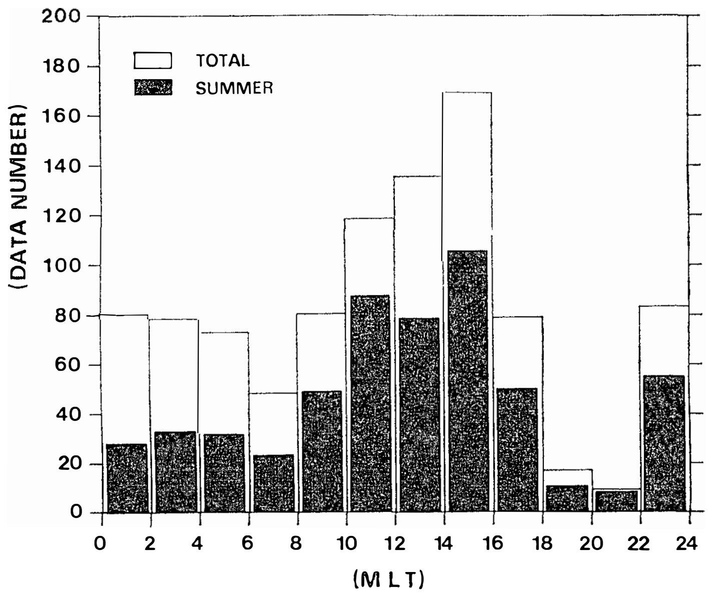


Fig 2 Data number for each 2 magnetic local hours that we used in the analysis.

several kinds of FAC's are actually observed as shown in Fig. 3. Single-sheet structured FAC denoted here (type 1 and 2, flowing into and away from the ionosphere) and double-sheet structured one (type 3 and 4 here, flowing into the ionosphere at higher latitude and flowing away from at lower latitude, and its reverse type) are most typical,

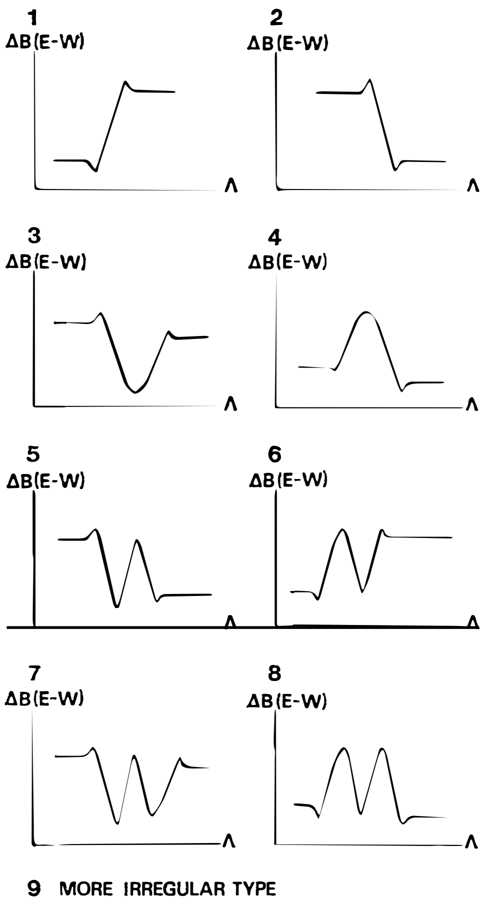


Fig. 3. Classification of magnetic field perturbations measured by TRIAD's magnetometer. Types 1 and 2 are referred to as 'single layer' FAC and types 3 and 4 are called 'double layer' FAC.

although triple- or quadruple-sheet structured FAC's are occassionally observed especially in the midnoon and midnight region. We analyzed only single- and double-sheet structured FAC whose magnetic field perturbations are larger than 100 nT (J=0.08 A/m). In this analysis, the definitions of double- and single-sheet structured FAC's are as follows: When magnetic field perturbations are observed in close vicinity of each other and smaller amplitude perturbation is two tenth larger (smaller) than the dominant one, we defined them as double- (single-) sheet structured FAC. Furthermore, these magnetic field perturbations observed by the TRIAD satellite often include long period ($\sim$10 min) variation as well as short period variation ($\lesssim$60 s). It has been thought that the latter shows FAC phenomena and the former is caused by instrumental and artificial variations. Recently, APL Johns Hopkins University group succeeded to ascertain the cause of long period variation and to exclude this variation (POTEMRA, 1979; private communication). Until corrected data are available, we try to select FAC events by the following criterion. When we find data that has two kinds of magnetic field perturbation, one is short-lived ($\lesssim$60 s) and another is long-lived ($<$10 min), almost always two kinds of base lines x and y can be drawn around

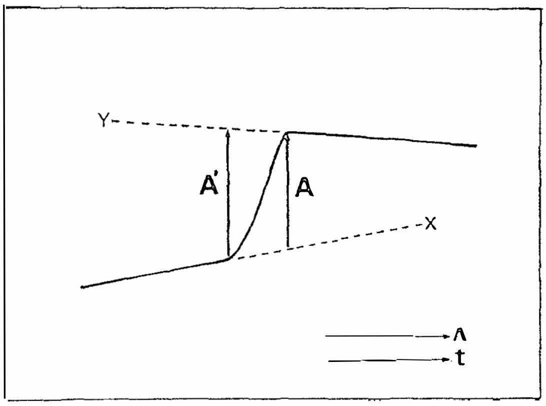


Fig 4 How to reduct the magnetic field data obtained by TRIAD is shown. Base lines x and y for measuring magnetic field perturbations are displayed.

the short-lived variation as shown in Fig. 4. For both transverse components of magnetic field perturbation (A, B) and (A', B') those are measured from base lines x and y respectively,

$$\left|\frac{A-A'}{A+A'}\right|<0.1 \qquad \left|\frac{B-B'}{B+B'}\right|<0.1$$

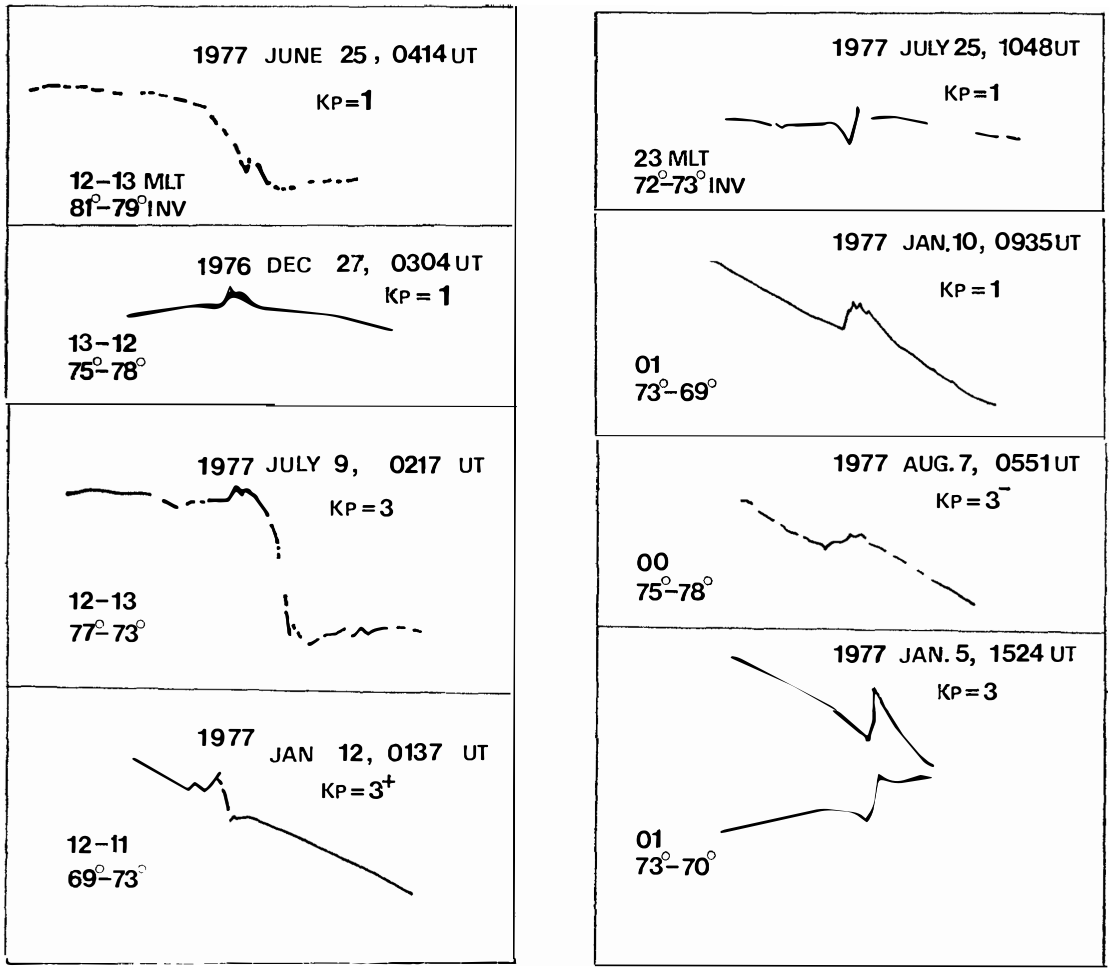
If these conditions were satisfied, we used this data The value of FAC amplitudes those we adopted were $(A+A')/2$ and $(B+B')/2$ respectively. Therefore intensity of FAC's in our analysis inevitably had an error of 10%

3. Seasonal Variation of FAC

We analyzed the TRIAD magnetic field data observed in northern summer (April 24–August 23) and northern winter (October 24–February 23) which were received at Resolute in 1976 and 1977 and received at College in 1973 and 1974. We used the value of Kp index as a measure of the level of magnetospheric activity: for quiet stage $Kp \leq 2$ and for rather disturbed stage $2 < Kp \leq 4$.

3.1. Seasonal variations of FAC intensity

Seasonal variations of FAC intensity were analyzed in every 2-hour segment of MLT. As seen from Fig. 2, the sampled number of data in every segment is not homogeneous, especially during the interval of 18–22 MLT. Examples of FAC intensity in summer and winter on the dayside and nightside are displayed in Figs. 5a, b. Seasonal variations of FAC intensity those were obtained by averaging over every 2-hour MLT segment during same geomagnetic activity are shown in Figs. 6a–h. Figs. 6a–h show that on the dayside there are definitely seasonal variations in FAC intensity, namely $FAC_{summer} > FAC_{winter}$, however, on the nightside no definite seasonal variations are discernible. Fig. 6 also shows that FAC amplitude depends upon



(a) (b)

Fig. 5 Summer and winter typical examples of FAC's (a) in the dayside and (b) nightside region for quiet and disturbed conditions

geomagnetic activity. Intensity of FAC's observed during disturbed stage ($2<Kp\leq 4$) is larger than that for quiet stage ($Kp\leq 2$) in both summer and winter. In each season for each geomagnetic stage, the single structured downward FAC has a maximum peak of intensity around 8–10 MLT and in the evening it decreases gradually with increasing MLT, and the upward single structured FAC has a maximum peak of amplitude around 14–18 MLT and in the morning it also decreases with decreasing MLT. In the dayside between 8 and 16 MLT large seasonal variation can be obviously seen for both single and double structured FAC and for both $Kp\leq 2$ and $2<Kp\leq 4$ conditions. The FAC intensity in summer is larger than that in winter. The maximum value of the ratio of the intensity of FAC (summer/winter) exceeds 3 times during the period 10–14 MLT for upward FAC when Kp is $2<Kp\leq 4$, whereas no seasonal varia-

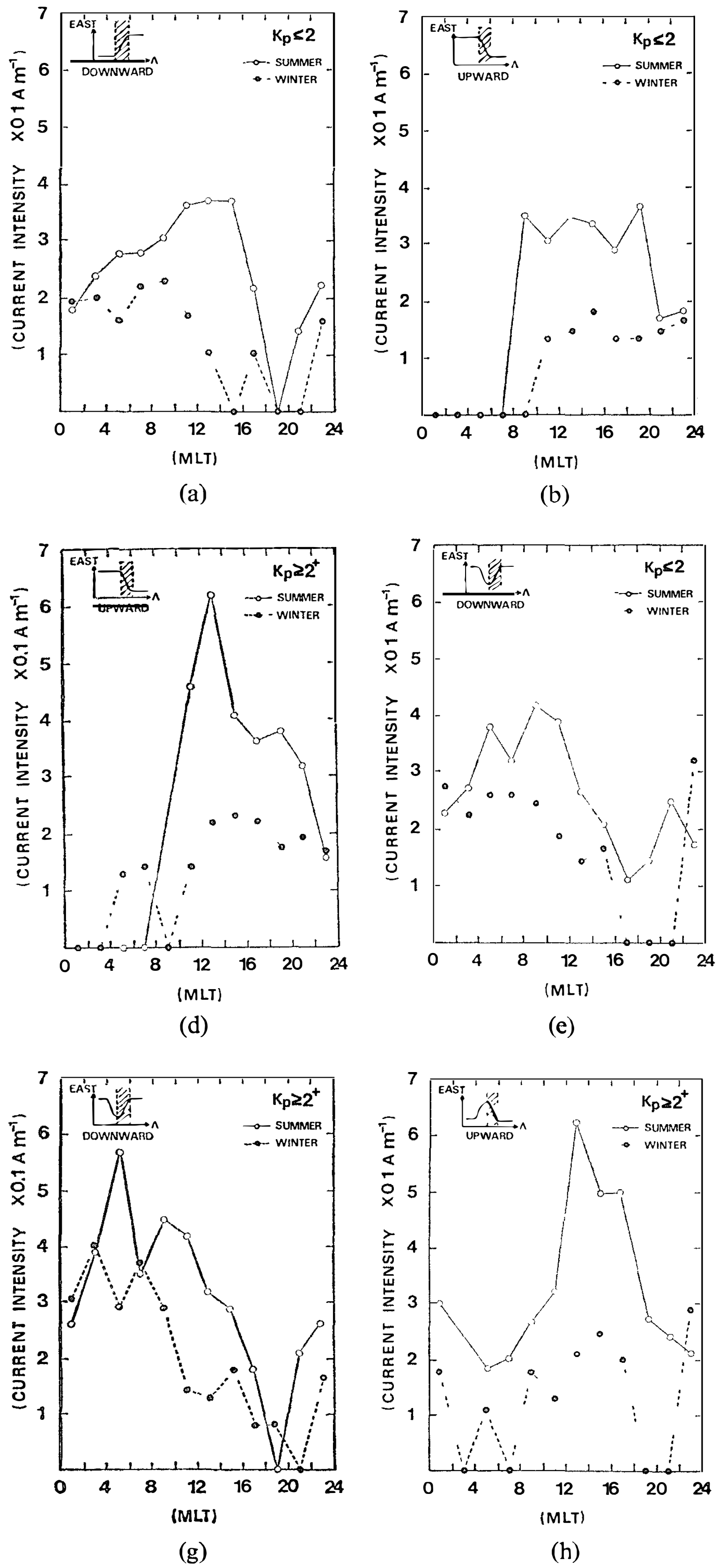
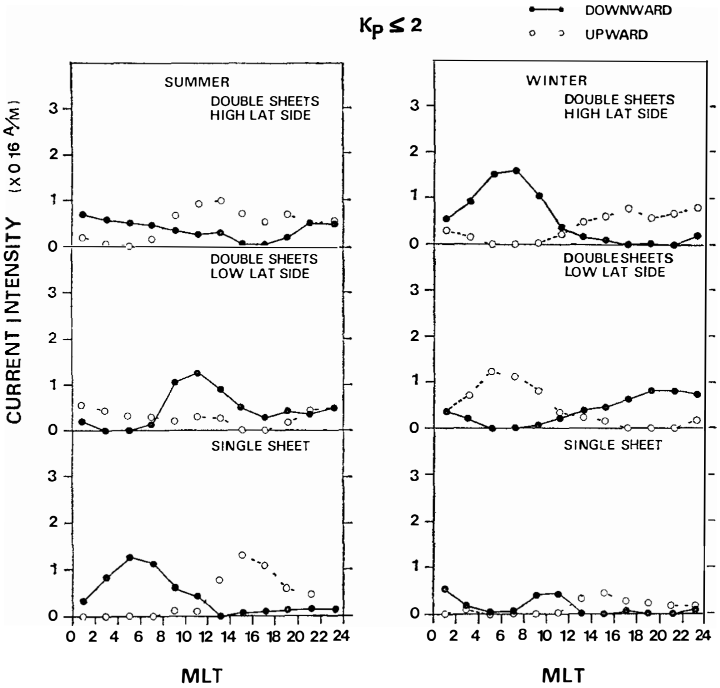
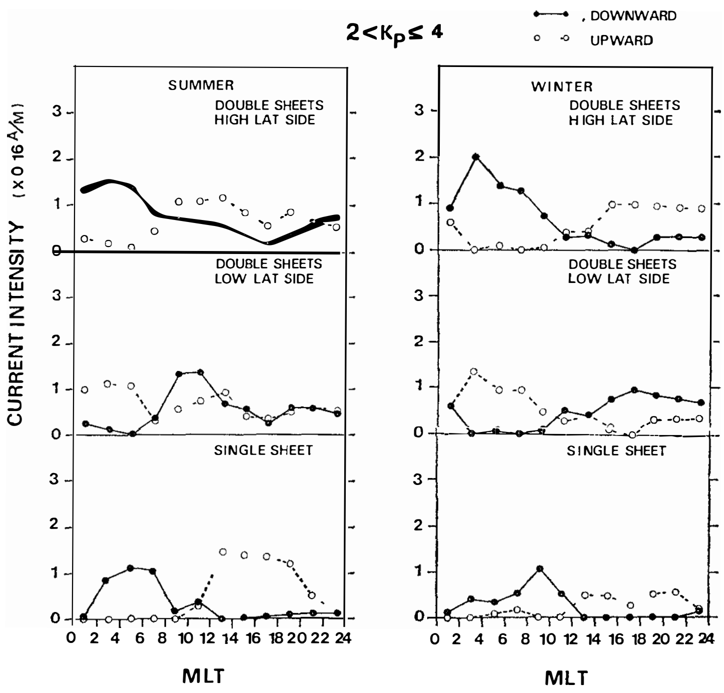


Fig 6a–h. Seasonal variations of FAC intensity against magnetic local time for quiet and disturbed stages.



(a)



(b)

Fig. 7. Seasonal and longitudinal distribution of FAC expected values for (a) quiet and (b) disturbed conditions. Expected value means that the intensity of a certain kind of FAC is multiplied by its occurrence probability.

tions can be seen in the nightside region. In addition the region of maximum intensity moves toward the nightside region with increasing geomagnetic activity as shown in Figs. 6c and d, f and g in same geomagnetic activity. The results given in Fig. 6 show the simply averaged value of FAC intensity for the sampled data in each MLT segment and the occurrence probability of single structured FAC (type 1 and 2) and double structured FAC (type 3 and 4) is not taken into account. When we want to know the expected value (actual value) of FAC intensity in each MLT segment, we must multiply the intensity of a certain type of FAC displayed in Fig 6 by its occurrence probability Expected values of FAC's are mentioned later in this paper

3.2. Expected value of FAC and current balance

Fig. 7 displays expected values of FAC's. The intensities of higher and lower latitude side FAC's of double-sheet structured are separately shown in the upper and middle panels and the bottom shows the intensity of single-sheet structured FAC. The shape of expected value of the intensity of each FAC type resembles the intensity of each type of FAC shown in Figs. 6a–h (simply averaged value). Intensities of FAC's exhibit seasonal variations as well as the dependence on geomagnetic activity. For both $Kp \leq 2$ and $2 < Kp \leq 4$ and both summer and winter the maximum regions of single structured FAC intensities are closer the midday than those of the double structured FAC. Furthermore, on the dayside the seasonal variations of single structured FAC's are much greater than those of double structured one. Expected value of single structured FAC in summer is much greater than that in winter whereas expected value of double structured in summer is nearly same as that in winter The expected value profile of higher latitude FAC is very similar to that of lower latitude one, although the current direction is inverse to each other. Therefore, higher and lower latitude FAC's nearly cancel out (a balance) with each other in a meridian plane. The single structured FAC in the dawn sector should mainly cancel out with that in the dusk sector, because total input of FAC is equal to output of FAC as mentioned later.

In summer the total amount of FAC input (output) is larger than that in winter. It is also found that the total amount of FAC input and output increase with increase in Kp value. Balance between input and output FAC is given in Table 1 for summer and winter and for $Kp \leq 2$ and $2 < Kp \leq 4$ conditions. In one hemisphere FAC input and output are balanced with each other in both seasons for every Kp value within the error less than $\pm 10\%$. The current input (which is equal to current output) integrated over the whole MLT region is equal to 3.0×10^6 A in summer for $2 < Kp \leq 4$ and 2.0×10^6 A for $Kp \leq 2$, and in winter it amounts to 2.5×10^6 A for $2 < Kp \leq 4$ and 1.9×10^6 A for $Kp \leq 2$. The ratio of total amount of FAC input and output in winter to that in summer for disturbed condition ($2 < Kp \leq 4$) is larger than that for quiet con-

Table 1 Total amount of FAC ınput and output
+. Current that flows ınto the ıonosphere
–· Current that flows out of the ıonosphere.

	Summer		Wınter	
	Downward	Upward	Downward	Upward
$Kp \leq 2$	2 1	−1 9	2 0	−1 8
$2 < Kp \leq 4$	2 8	−3 2	2 6	−2 4

Unıt ıs 10^6 A

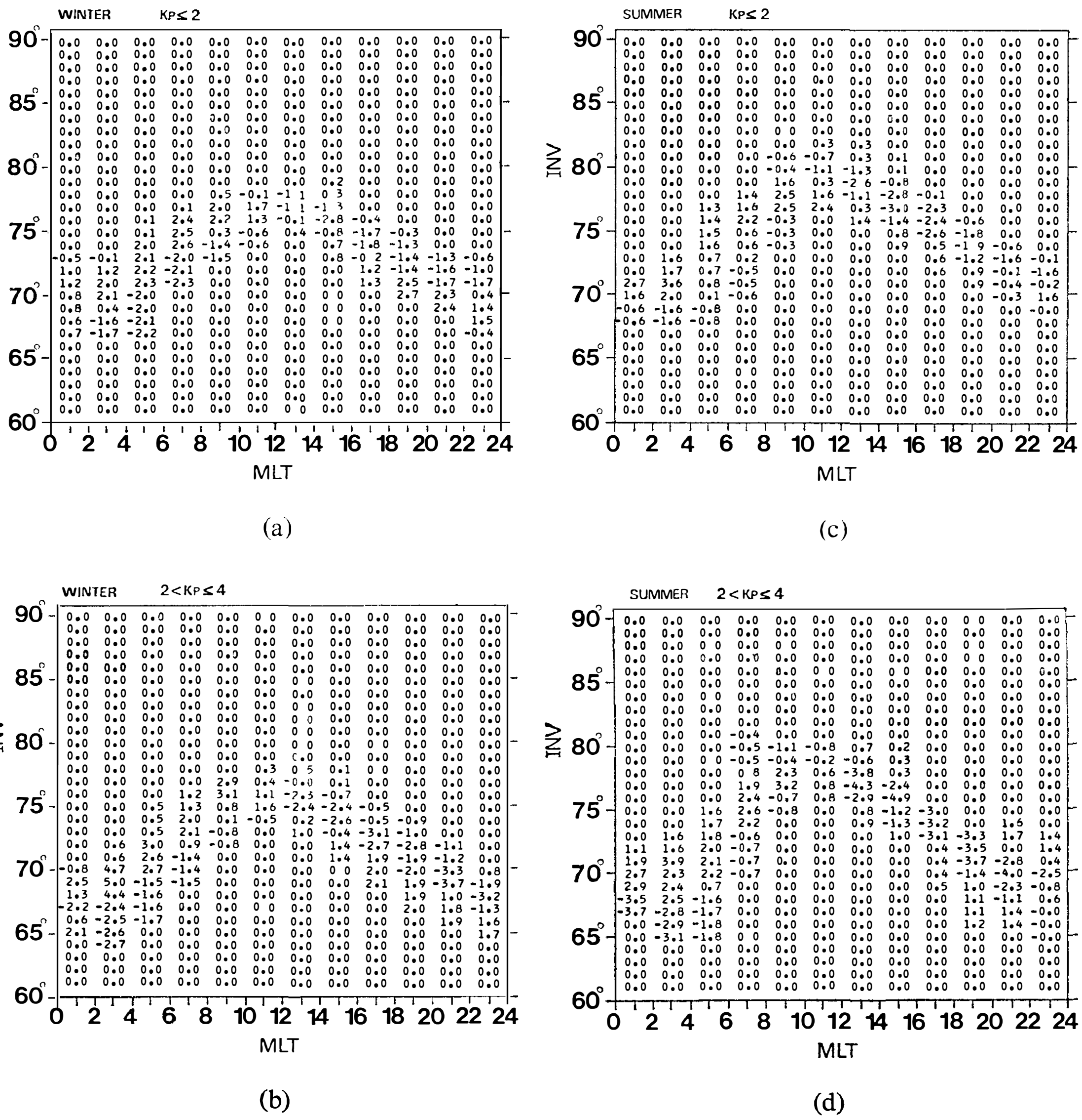


Fıg 8a–d Statıstıcal dıstrıbutıon of FAC's ın whıch locatıon (MLT, INV) and ıntensıtıes of FAC's are taken ınto account for each season and foı each actıvıty stage

dition ($Kp \leq 2$). These values are less than the ratio of the total FAC for $Kp \leq 2$ to that for $2 < Kp \leq 4$. Statistical distribution of FAC's at the altitude of 800 km in which location (MLT, INV) and intensities of FAC's are taken into consideration is shown in Fig. 8. The values shown in Fig. 8 indicate arithmetic total of type 1, 2, 3, and 4 FAC's. When downward and upward FAC's statistically flow into and out of same region on the ionosphere and downward FAC intensity is equal to upward one, FAC intensity there is equal to 0. Ionospheric currents in the middle and low latitudes are mainly controlled by this FAC distribution.

It has not been known yet how higher latitude FAC's connect with lower latitude FAC's and how single structured FAC's connect with each other, although the downward and upward FAC's should be closed with each other by the ionospheric current. From our analysis it is speculated as follows. Dominant part of the higher latitude FAC's seem to connect with lower latitude one in a meridian plane. Little part of higher latitude FAC's in the dawn (dusk) sector seem to connect higher latitude FAC in the dusk (dawn) across the polar cap or along the auroral zone or with lower latitude FAC in the dawn (dusk) longitudinally. The connection among the FAC's by ionospheric currents cannot be known until numerical calculation with FAC distributions in this paper and with realistic conductivity model is done.

3.3. Seasonal variation of FAC location

Latitude of FAC location varies with seasons. Fig. 9 shows the seasonal variation of location of the higher latitude side FAC. The seasonal variation of the location is distinguished in the dayside region. However, in the nightside region it is not clear, probably because we analyzed FAC events without distinction of substorm stages (expansion and recovery phase). When substorm occurs, at first aurora around midnight moves equatorward and explodes abruptly, then moves poleward. FAC location may also moves equatorward or poleward associated with auroral zone moving equatorward or poleward, because FAC phenomena occurs in the vicinity of auroral zone (MCDIARMID *et al.*, 1978). Since we did not distinguish these two stages of geomagnetic activities, in this analysis we restricted our interest on the dayside region. The latitude of FAC location in summer is higher than that in winter around midnoon region (Fig. 9) in the same geomagnetic activity. In one season the latitude of FAC location decreases with increase of geomagnetic activity. In addition FAC at midnoon has very complex structure shown in Fig. 9. The lower and higher boundary of higher part of FAC (type 3 and 4) has a kink around midnoon. Sometimes the lower boundary in the pre-noon (post-noon) region nearly coincides with the higher boundary of single structured FAC in the post- (pre-) noon region.

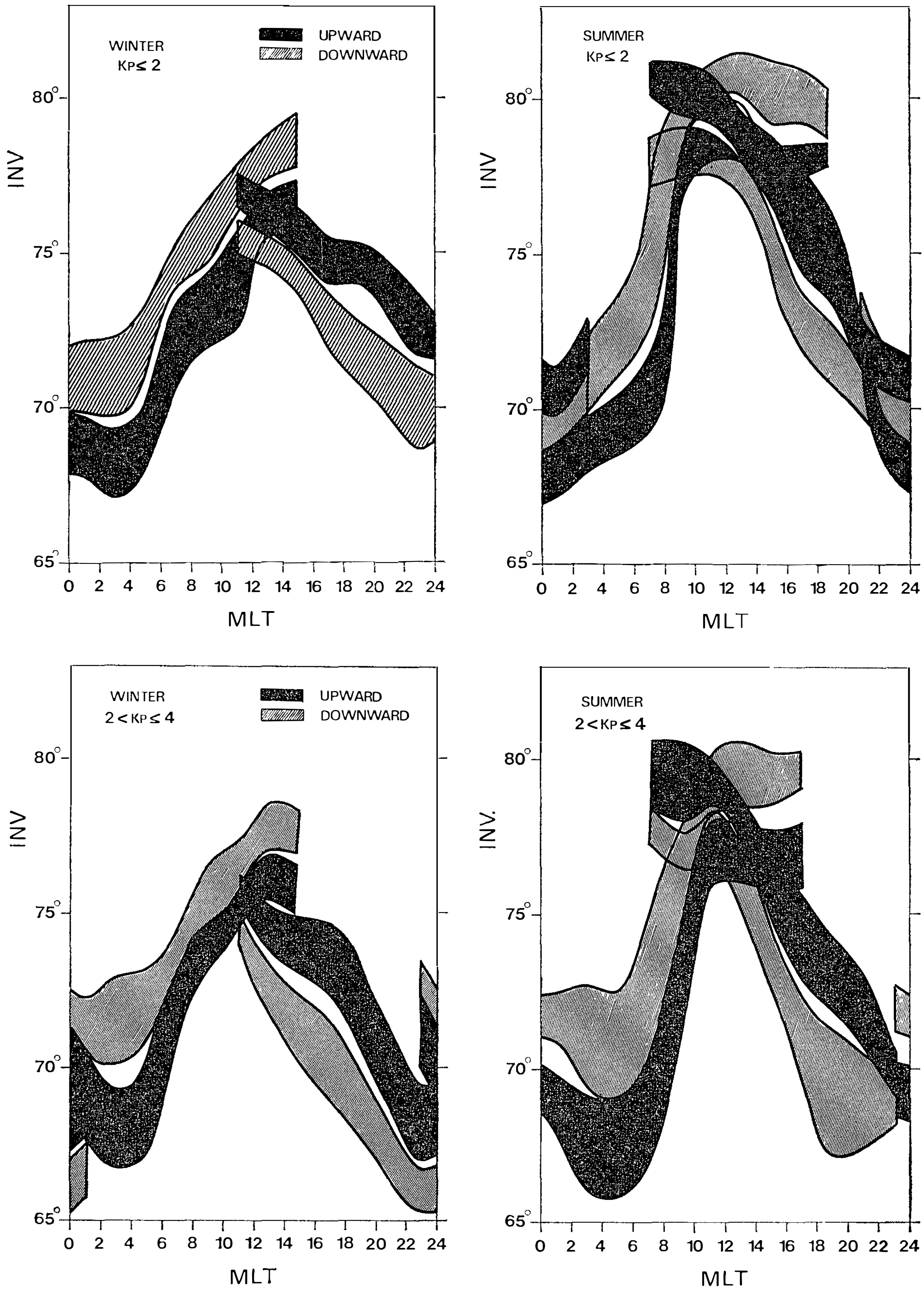


Fig 9. Seasonal variations of FAC location for each magnetospheric activity and for each season

4. Conclusion and Discussion

In the previous section we have gotten the following results about the seasonal variations of FAC.

1) In the dayside region the intensity of FAC varies with seasons. Intensity of FAC amplitude in the summer season is larger than that in the winter season Largest seasonal variation can be seen in 10–14 MLT (ratio of the FAC intensity in summer to that in winter is about 2–3) In addition it is interesting to consider that the seasonal variation during the period 6–10 MLT is smaller than that during the period 14–18 MLT In the nightside region there are no seasonal variations.

FAC intensity is related with ionospheric parameters by the equation $J_{/\!/}=-\operatorname{div}(\sigma E)$, σ denotes height-integrated ionospheric conductivity tensor. Then FAC intensity is related with electrical conductivity and local electric field (local distribution of electric field is induced from large scale electric field). Ionospheric conductivity is producted by energetic particle precipitation and EUV radiation. Since ionospheric conductivity producted by EUV is determined by solar zenith angle and ambient neutral atmospheric composition and abundances in the ionosphere, it varies with season. On the contrary it has not been known yet whether global patterns of particle precipitation has a seasonal variation or not. Since in the dayside region ionization by EUV is usually greater than that by particle precipitation (VAN'YAN and OSIPOVA, 1975), and the dayside region electrical conductivity producted by EUV has more smooth variations than that producted by precipitation, FAC intensity is principally related to the electric field divergence not by conductivity gradient, FAC may be written roughly by the equation,

$$J_{/\!/}=-\sigma_p \operatorname{div} E$$

As for the electric field the existence of the seasonal variation in the auroral oval has not been examined yet, though electric field amplitude in the polar cap may vary with seasons been examined yet, though electric field amplitude in the polar cap may vary with seasons (KAMIDE, 1979; private communication). No one knows how the magnetospheric deformation by the different tilt angle of the earth rotation to solar wind flow with seasons influences on the electric field and how the seasonal variation effects the electric field. If there are no north-south asymmetry for electric field, *i.e.*, geomagnetic field line is closed where FAC flows into or out of ionosphere and electrical equipotentiality is conserved on every closed field line (there is no parallel electric field)

$$\frac{J_{/\!/\text{summer}}}{J_{/\!/\text{winter}}}=\frac{\sigma_{\text{summer}}}{\sigma_{\text{winter}}}.$$

From the paper written by VAN'YAN and OSIPOVA (1975),

$$\frac{\sigma_{\text{summer}}}{\sigma_{\text{winter}}}=2\,. \quad (10\text{–}14 \text{ MLT, INV}=78°)$$

This conductivity ratio between summer and winter is same as the ratio of $J_{/\!/\text{summer}}$ to $J_{/\!/\text{winter}}$ known from our analysis. It is easy to explain why there is no remarkable seasonal variations in the intensity of FAC observed in the nightside region. In the nightside region auroral zone electrical conductivity is determined mainly by particle precipitation and electrical conductivity is nearly constant in this region through all seasons, then, (if we assume that electric field does not vary with seasons) the seasonal variation of FAC intensity cannot be found. In addition the reason why seasonal variations of FAC intensity in the post-noon region are greater than that in the pre-noon region may be related with the observation by McDiarmid *et al.* (1978) that particle precipitation with the energy (10 to 20 keV) in the post-noon region is 10% of that in the pre-noon region.

2) In double-sheet structured FAC's the higher latitude FAC is nearly cancelled out with the lower latitude FAC in a meridian plane. Resultantly as the total sum of the single structured and double structured FAC's in the morning region downward FAC flows into ionosphere and in the evening region upward FAC flows out of ionosphere.

The statistical results on the balance of FAC suggests that higher latitude FAC's cannot be balanced with each other and they should be connected with lower latitude FAC's (Fig. 10). Region 1 FAC reported by Iijima and Potemra (1976a) obviously corresponds to higher latitude FAC in this paper and region 2 FAC corresponds to lower latitude FAC except for the midnoon and midnight region of the complicated

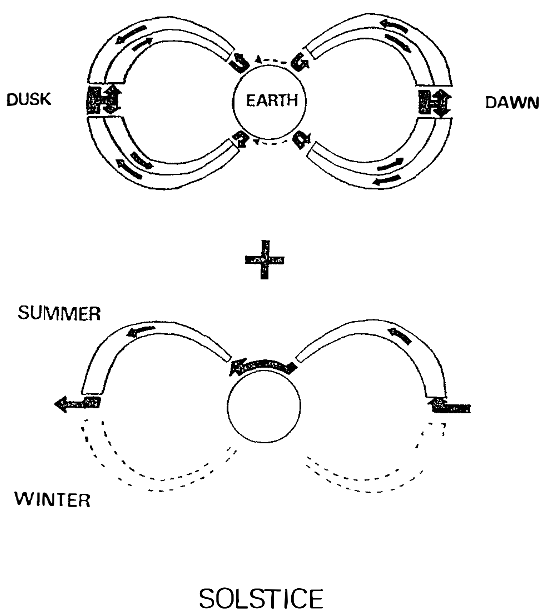


Fig 10 FAC's flow model derived from this analysis

distribution of FAC direction. IIJIMA and POTEMRA pointed out that region 1 and 2 FAC have different dependence upon geomagnetic activity, AL, and inferred that region 1 and 2 FAC's have different sources, respectively. However, our analysis shows that region 1 FAC is connected with more than two kinds of ionospheric currents, namely, region 1 FAC has a branch of current circuit. One current circuit is that region 1 FAC is connected with region 2 FAC in a meridian plane (latitudinally). Another one is not known yet. It will be useful to calculate stream lines of the two-dimensional ionospheric current from the FAC distribution derived in this paper.

3) Expected value of single structured FAC in summer is much greater than that in winter whereas expected value of double structured one in summer is nearly comparable to that in winter. The maximum intensity region of single structured FAC in winter is located at more dayside region than that in summer.

Differences of dependence upon seasons between single- and double-sheet FAC's during the interval from 6 MLT to 18 MLT gives us an information how FAC's connect with ionospheric current and how FAC's connect with each other. Nearly non-seasonal variations in expected value of double-sheet structured FAC may show that higher latitude side FAC (region 1) connect with lower latitude side FAC (region 2) in the same meridian plane in the auroral zone. The non-seasonal variations of the FAC is attributed to a non-seasonal variation of particle precipitation which governs electrical conductivity in the auroral zone. Large variation of FAC expected value of single-sheet structured may show that this type of FAC flows in the polar cap region from dawn to dusk in the summer season whereas it does not flow in the polar cap in the winter season, because conductivity in the polar cap in almost determined by solar EUV radiation and it is much larger in summer in comparison with winter (Fig. 10). There may be dominantly two possible FAC mechanism. One is that region 1 FAC is created by magnetospheric convection and region 2 FAC is producted by charge separation in the magnetosphere (Alfvén layer) and the other is that region 1 and 2 FAC's are created together, for example, by magnetospheric dynamo (ROSTOKER and BOSTROM, 1976). It is very interesting to consider how and when these FAC's connect with each other. The FAC's may be created actually by both mechanism.

4) From the analysis of the data observed at the northern high latitudes, each type FAC (single and double structured) is balanced by itself within the error of 10%.

This does not deny that FAC in the northern high latitude cannot connect with FAC in the southern high latitude. However, approximately FAC's in one hemisphere is considered to be closed with each other and not to connect with FAC's in another hemisphere For each magnetospheric activity total input and output FAC current in summer was larger than that in winter.

5) After separating the effect of seasonal variations of FAC's, there remains the

dependence of FAC upon geomagnetic activity. With geomagnetic activity increasing, FAC intensity increases. The contribution of seasonal variations to total current input and output is less than that of geomagnetic activity variation from $Kp \leq 2$ to $2 < Kp \leq 4$. However, the contribution of seasonal variation to FAC's for each 2-hour MLT segment cannot be neglected.

6) FAC location varies with seasons especially in the dayside region. Location in summer are higher than that in winter in the dayside region.

This tendency was reported by the seasonal variation of magnetospheric magnetic field (MEAD and FAIRFIELD, 1975) and seasonal variation of the location of auroral electrojets inferred from the ground-based magnetic field data (NAGAI and FUKUSHIMA, 1979). Solar wind flow will deform the dayside magnetospheric magnetic field as displayed in Fig. 11. The FAC location in the nightside region inferred to be lower in summer than that in winter. These suggest that the conjugate point determined from FAC varies with seasons.

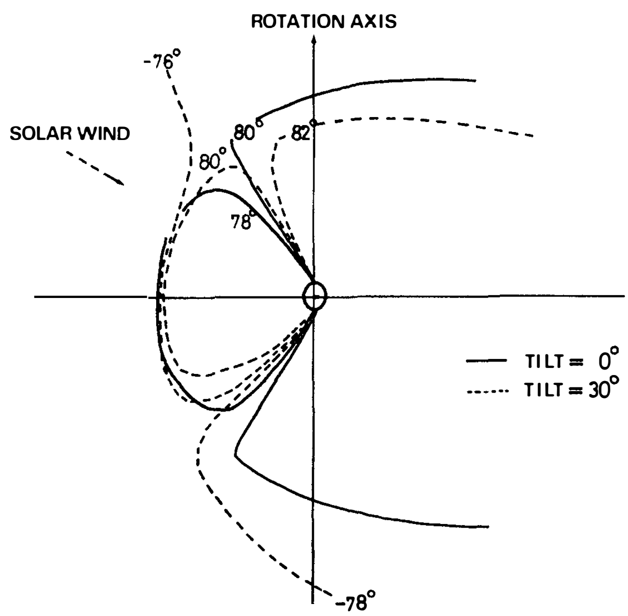


Fig 11. Seasonal variation of geomagnetic field. Geographic latitude that corresponds to outermost geomagnetic field line at dayside varies with seasons, 80° in summer and 78° in winter.

7) It was found that the distribution of FAC location has complicated form in the midday region.

The FAC location (*e.g.*, location of higher latitude side FAC) does not form a part of circle, but a kink. This kink is consistent with cusp FAC proposed by IIJIMA *et al.* (1978). We have already showed that the occurrence probability of highest part of FAC which is constituted by downward current at higher latitude and upward current at lower latitude (a pair of inverse direction FAC) has two peaks. One is positioned in the dawn (dusk) and another is located at post- (pre-) noon. We implied that the FAC located at post- (pre-) noon is different type of FAC from region 1 FAC and that cusp FAC is no the longitudinal extension of region 1 FAC. We examined once more the cusp region FAC from a different point of view, location of FAC. When cusp FAC is found, the lower latitude one may coincide with region 1 FAC.

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