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DERIVATION OF POLAR CAP AE INDICES

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Abstract: We have derived on a test basis a geomagnetic index by using presently available data in the southern polar cap. Observatories used here are Scott Base, Dumont d'Urville, Vostok and Mirny. To derive disturbance fields a base value of each station for each month is first calculated using a moving average method, and this base value is subtracted from hourly data from the station in that month. Then after a coordinate transformation the largest and smallest values are selected from the four stations, respectively in the same way as the AU and AL indices are derived, and we call them the polar cap AU and AL indices. The difference between these values gives the polar cap AE index, and we derived these indices for the H and D components and T, the total force of the geomagnetic field for the years 1966 (near solar activity minimum) and 1980 (near solar activity maximum). The results of the variation of the disturbance fields from the four stations show a clear diurnal and seasonal variation depending on distribution of the stations and the ionospheric conductivities in the southern polar cap. We find the highest correlation between the polar cap AE indices and the AE, AU, and AL indices in the local winter, and the correlation decreases in the local summer due to the increase of the ionospheric conductivity in the polar cap caused by solar UV radiation. The relationship between the IMF B_y component and the polar cap AU index during local summer seems to be quadratic. The results indicate that both positive and negative B_y increase the value of the polar cap AU index due to enhancement of the B_y dependent currents in the polar cap.

1. Introduction

A polar cap magnetic activity index was first defined by FAIRFIELD (1967), after examining the magnetic activity in the polar cap by using three stations, Thule, Alert and Resolute Bay. He defined a polar cap index by the maximum horizontal disturbance at these stations. KOKUBUN (1971, 1972) also used a similar index for his investigations. TROSHICHEV *et al.* (1979) proposed to use a single near-pole station to derive a magnetic activity index PC, which would be regarded as a signature of the magnetic activity driven by the IMF B_z component. In a later study TROSHICHEV *et al.* (1988) concluded that the PC index shows a good statistical correlation with the southward component of IMF. Thus the PC index derived by them is not constructed to monitor the currents associated with the northward component of IMF.

The polar cap AE indices proposed here differ from the index by TROSHICHEV *et al.* The method of derivation of the new indices is similar to the procedure taken by FAIRFIELD and KOKUBUN, but one of the important differences is that the present indices are based on data from four stations in the southern polar cap. We used the data from the stations in the southern polar cap because the northern polar cap is mostly occupied by the Arctic Ocean. More importantly, we choose these stations because Automatic Geophysical Observatories are being planned to be set up on the Antarctic Continent. Another important difference is that we have derived, though it is on a test basis, the present indices for the H and D components and T, the total force of the geomagnetic field.

One of the aims of deriving the present indices is to monitor the ionospheric currents over the polar cap during northward IMF, because the auroral oval contracts poleward in association with the northward turning of the interplanetary magnetic field, to such an extent that the AE index stations cannot measure the less intense electrojet current flowing at higher latitudes. Satellite observations have shown that under these conditions the large-scale field-aligned current system usually existing during magnetically active conditions breaks down into irregular structures confined to the region of higher geomagnetic latitudes.

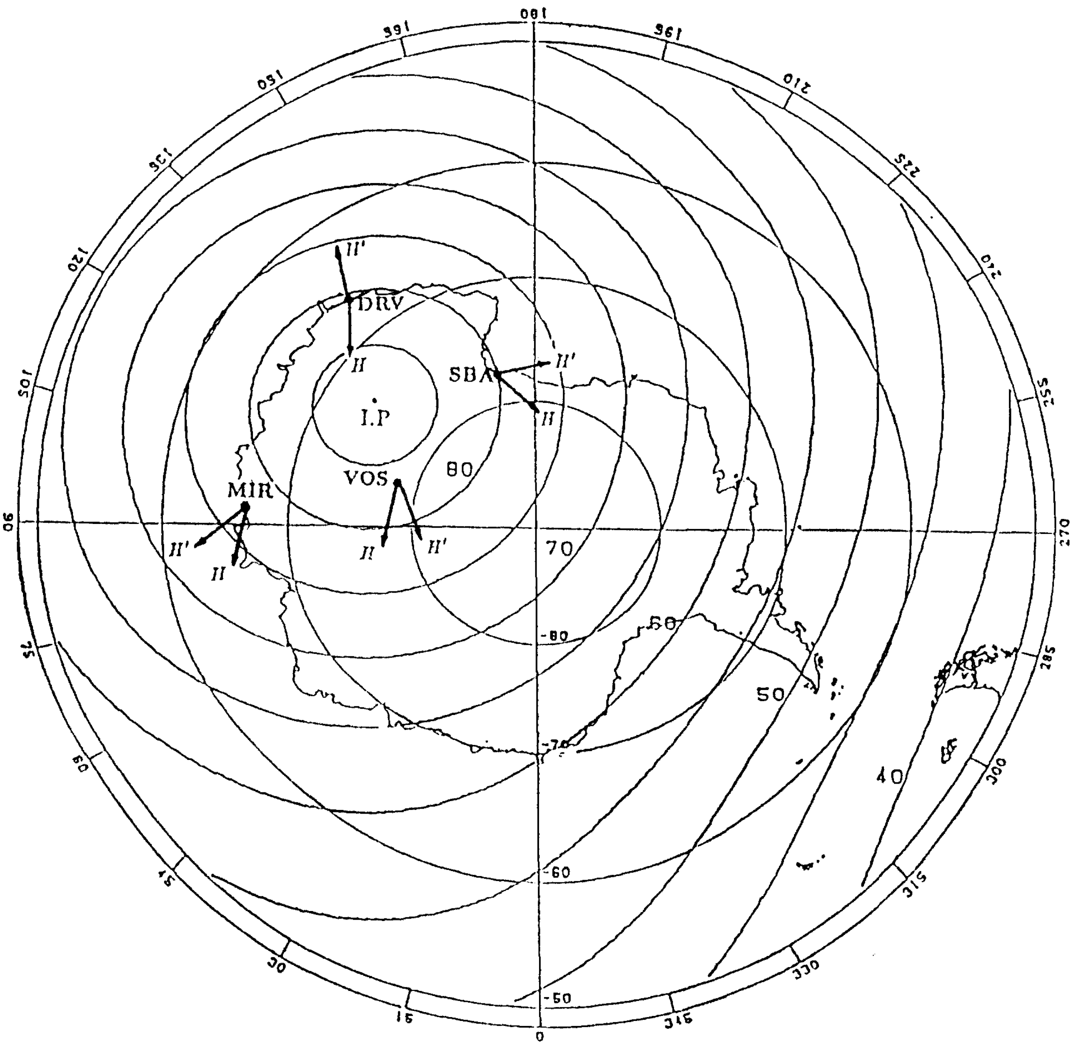
In order to monitor the intensity of the ionospheric current and field variations over the polar cap during northward IMF, it is desirable to derive the polar cap magnetic indices in the same way as the AE indices are derived. The electrojet index AE was developed by DAVIS and SUGIURA (1966) in order to provide a means by which the intensity of the electrojet is monitored on a continuous basis. In deriving the polar cap AE indices it is desirable to use as many observatories as possible with a uniform distribution in longitude. Since there are only a limited number of polar cap magnetic observatories and the northern polar cap is mostly occupied by the Arctic Ocean, it is unavoidable to find a practical compromise for selecting the stations.

2. Method of Calculation

We derive on a test basis a new polar cap geomagnetic index by using presently available data in the southern polar cap. Observatories used here are Scott Base (geomag. coord. $-78.84°$, $293.24°$), Dumont d'Urville ($-75.06°$, $232.15°$), Vostok ($-89.31°$, $139.62°$) and Mirny ($-76.80°$, $151.15°$) as illustrated in the Fig. 1. To derive disturbance fields a base value of each station for each month is first calculated using 13 months moving average method, and this base value is subtracted from hourly data from the station in that month. Then the largest and smallest values are selected from the values for the four stations, respectively, in the same way as the AU and AL indices are derived. The difference between these values gives the polar cap AE index. Two of the stations (Scott Base and Dumont d'Urville) give the data in the X, Y and Z coordinate system rather than H, D and Z. Here D means the component normal to H, rather than the declination in angular measure.

As the directions of the main field vectors at the four stations are deviated

INVARIANT LATITUDE CONTOUR (1GRF85 MODEL)



DEOGRAPHIC COORDINATES

Fig. 1. Locations, in geographic coordinates, of the stations used in this study. H indicates the directions of the H component at each station and H' indicates the horizontal component in the direction of the invariant pole (I.P.)

from the invariant pole direction, we rotate the coordinates by an angle α so that the direction of the H' axis points to the invariant pole, using the matrix expression

$$\begin{pmatrix} \Delta H' \\ \Delta D' \end{pmatrix} = \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} \Delta H \\ \Delta D \end{pmatrix},$$

where $\Delta H = H - H_0$, $\Delta D = D - D_0$, H_0 and D_0 being the base line values of the H and D components, respectively. For the data in the X, Y, Z coordinate system, we rotate the coordinates by an angle β so that the direction of the H' axis points to the invariant pole, using the matrix expression

$$\begin{pmatrix} \Delta H' \\ \Delta D' \end{pmatrix} = \begin{pmatrix} \cos\beta & -\sin\beta \\ \sin\beta & \cos\beta \end{pmatrix} \begin{pmatrix} \Delta X \\ \Delta Y \end{pmatrix},$$

where $\Delta X = X - X_0$, $\Delta Y = Y - Y_0$, X_0 and Y_0 being the base line values of the X and Y components, respectively.

The total disturbance field can be calculated by the equation:

$$\Delta T = \sqrt{(\Delta H')^2 + (\Delta D')^2}.$$

We derive the polar cap AE index for the H ($PCAE_H$), D ($PCAE_D$), and T ($PCAE_T$) for the year 1966 (near solar activity minimum) and 1980 (near solar activity maximum).

3. Results and Discussions

The results of the variation in the disturbance fields from the four stations for the years 1966 and 1980 show a clear diurnal variation and seasonal variation. Figure 2 shows an example of the seasonal variation of the disturbance fields in the total intensity (T) from the four stations for the year 1966 during a quiet period. The diurnal variation is due to the longitudinal non-uniformity in the locations of the four stations, whereas the seasonal variation is due to the seasonal variation of

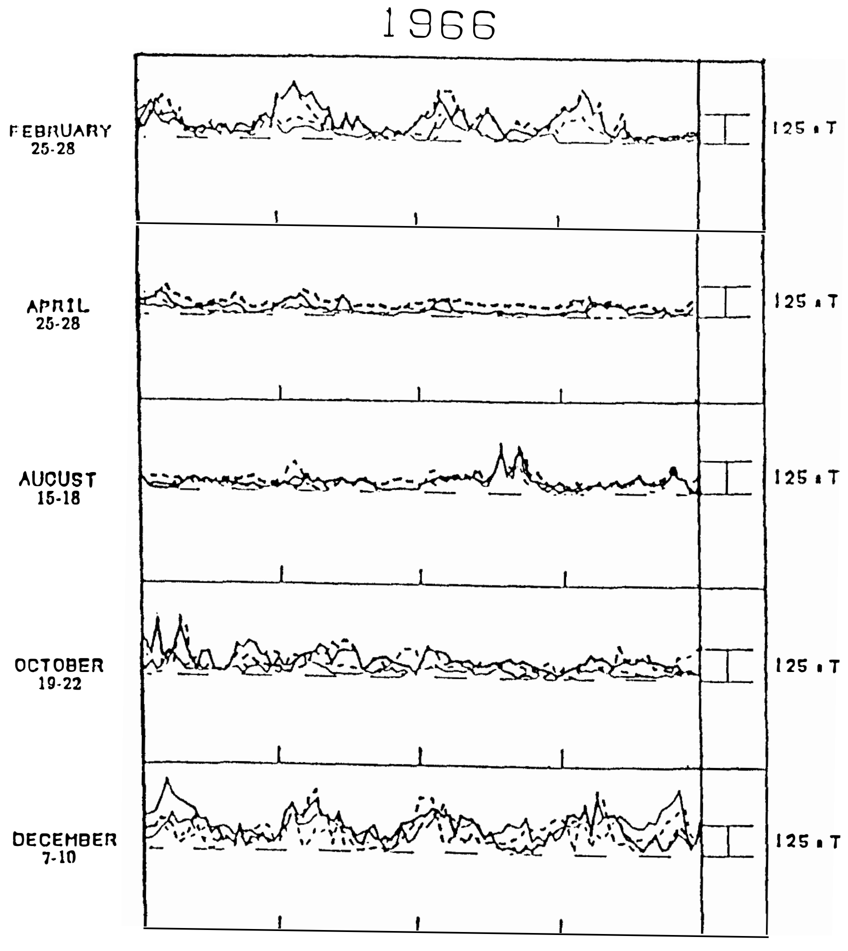


Fig. 2. The variations of the disturbance fields in the total force of the geomagnetic field (T) from four stations during a quiet period in 1966.

the ionospheric conductivity in the southern polar cap.

To investigate the relationship between the polar cap AE index thus derived and the auroral electrojet activity, we have examined the correlation between the $PCAE_H$, $PCAE_D$, $PCAE_T$ indices and the auroral zone indices AE, AU, and AL for the years 1966 and 1980, and found that the higher correlation is obtained with the AE index during local winter. Figure 3 shows the correlation coefficient between the $PCAE_H$ and the AE index for the years 1966 and 1980 during local summer and winter. Analogous figures (not shown) were obtained using the $PCAE_D$ and $PCAE_T$ indices with a similar correlation to the foregoing. The reason that for the highest correlation with AE among the AE indices (*i.e.* AE, AU, and AL), as is seen in Fig. 3, is probably that AU and AL are designed to monitor the eastward and westward electrojets separately, while the polar cap AE index and the standard AE index are suited to monitor the global activity in the polar cap and in the auroral oval, respectively. However, it is worth noting that the correlation with AL is almost as good as that with AE. The correlation with AU is seen to be strongly dependent on season, probably the seasonal effect on AU is stronger than on AL and the polar cap AE index. ALLEN and KROEHL (1975), MAYAUD (1980) and MURAYAMA *et al.* (1980) had previously noted that the annual variation of AU and AL shows a seasonal effect much more strongly in AU than in AL. The seasonal change is apparent not only in AU, but also in the polar cap AE index, although not as strongly as AU.

It can be seen from Fig. 3 that the correlation coefficient for the year 1980 (near solar activity maximum) is greater than for the year 1966 (near solar activity minimum). Figure 4 shows the correlation between the polar cap AE index and the auroral electrojet index (AE) for the years 1966 and 1980, and the correlation is better with the polar cap AE index for the H and D components than with T. Figure 5 shows the scatter plots between the $PCAE_H$ and the AE index during the summer and winter 1980, and it is seen that the correlation is much better during the winter than during the summer as is also seen in Fig. 3. The correlation coefficient between the polar cap AE index and the AE index decreases from local winter to local summer. We expect the decrease in correlation during summer as a con-

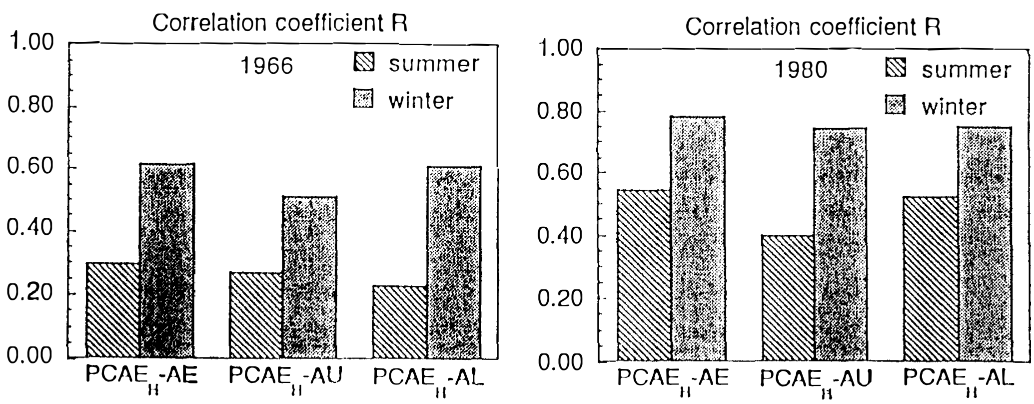


Fig. 3. Correlation coefficients between the $PCAE_H$ and the AE index for the years 1966 and 1980 during local summer and winter.

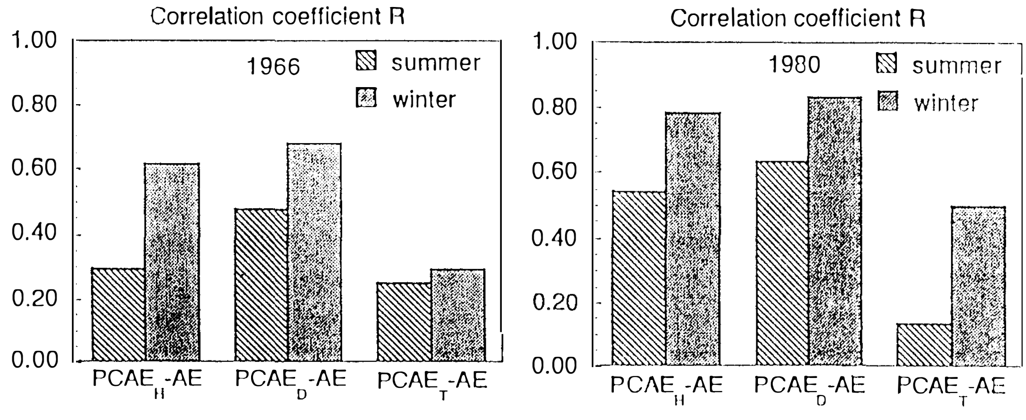


Fig. 4. *Correlation coefficients between the $PCAE_H$, $PCAE_D$ and $PCAE_T$ indices and the AE index for 1966 and 1980 during local summer and winter.*

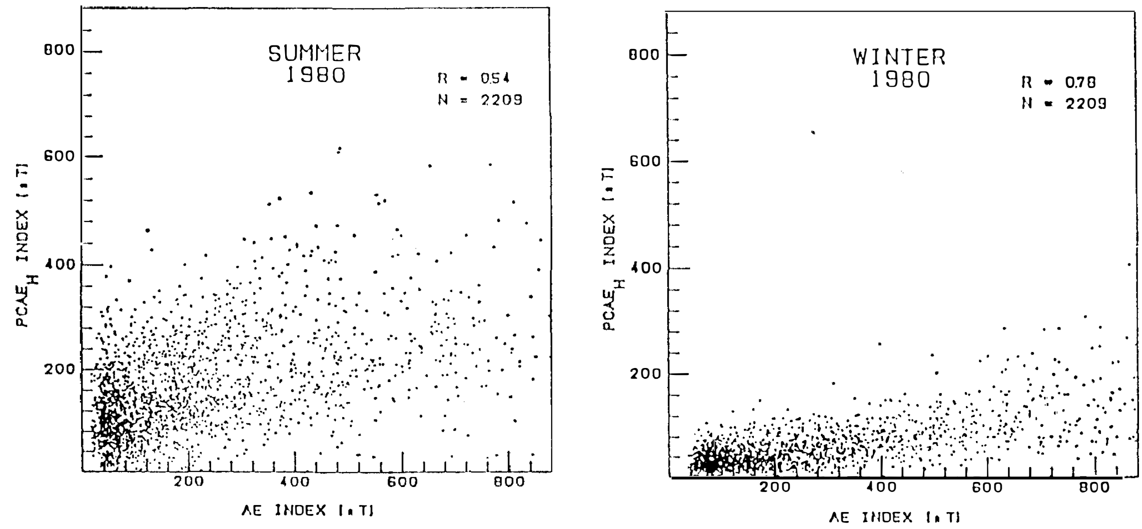


Fig. 5. *Scatter plot between the $PCAE_H$ and the AE index during local summer and winter 1980. The correlation coefficient R and the number of data points N are shown in each panel.*

sequence of the increase of ionospheric conductivity in the polar cap caused by solar UV radiation. This conductivity increase is accompanied by the development of ionospheric currents in the polar cap controlled by the B_y and B_z components of IMF, and the magnetic variations produced by these currents will reduce the correlation between the polar cap AE index and the AE index.

Although the AE index used here is calculated from northern hemisphere magnetic observatories records, it is possible to derive a similar electrojet index for the southern hemisphere. According to the study of the geomagnetic data from a large number of Antarctic stations, MACLENNAN *et al.* (1991) constructed a southern hemisphere AE index from 22 Antarctic stations and compared it to the corresponding northern hemisphere index. Their analysis showed a reasonable conjugacy for the AE north and south for the several days studied, despite of non-ideal locations of the stations in both hemispheres.

In order to understand the higher correlation between the polar cap AE index and the AE index during local winter than during local summer, as we have seen in Fig. 3, it is important to note that the contribution from the Hall currents is very small during winter, because the polar cap is in darkness and the ionospheric conductivities are very low, while during summer the contributions from both the Hall currents and the field-aligned currents in the oval are likely to be important. As is well known, during summer and northward IMF, reversed convection events (MAEZAWA, 1976; KUZNETSOV and TROSHICHEV, 1977) associated with the NBZ field-aligned currents (IIJIMA *et al.*, 1984) are often seen in the polar cap, and the currents in the polar cap are also very sensitive to the B_y component of IMF (FRIIS-CHRISTENSEN *et al.*, 1985). These currents are therefore likely to contribute to the decrease in correlation. ARAKI *et al.* (1984) concluded the existence of the vertical current associated with northward IMF from the results of a case study on the magnetic field pattern observed by MAGSAT and of a statistical analysis for the whole data period. We examined all the data of the *Z* component from the four stations in the southern polar cap during summer 1980 for IMF $B_z>0$ and $|B_y|<$ 2 nT. The *Z* component pattern in Fig. 6 is consistent with the ionospheric Hall current produced by a pair of field-aligned currents with a polarity opposite to the normal region 1 current.

During northward IMF an interesting difference between the polar cap AE index and the AE index may be noted. An example of this difference is seen on December 12–13, 1980, when the IMF B_z was kept northward almost throughout the day as is seen in Fig. 7. The figure shows that during the northward B_z period, rather large variations in the $PCAE_H$, $PCAU_H$ and $PCAL_H$ indices are seen, while AE, AU and AL stay close to zero. However, during the winter the polar cap AE, AU and AL indices also stay close to zero throughout the day, because the ionospheric conductivity in the southern polar cap is low and prevents electric currents from

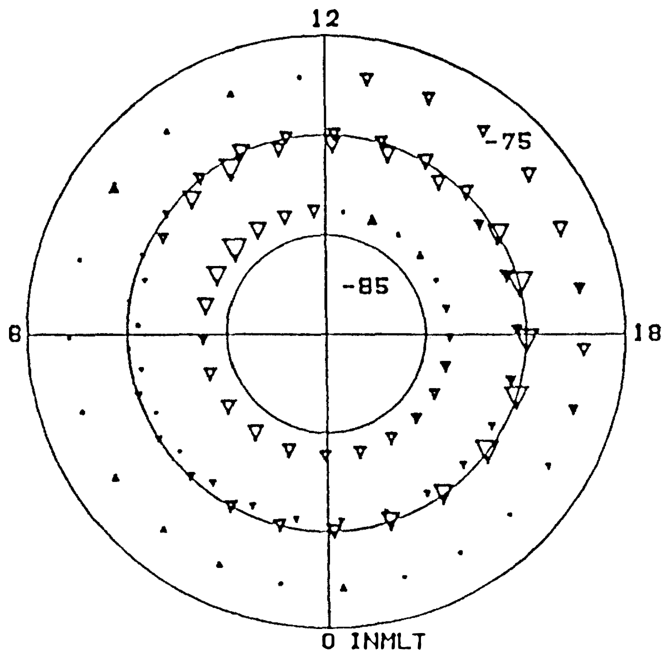


Fig. 6. Pattern of the averaged Z component from the four stations in the southern polar cap for IMF $B_z>0$ and $|B_y|<2$ nT during summer 1980.

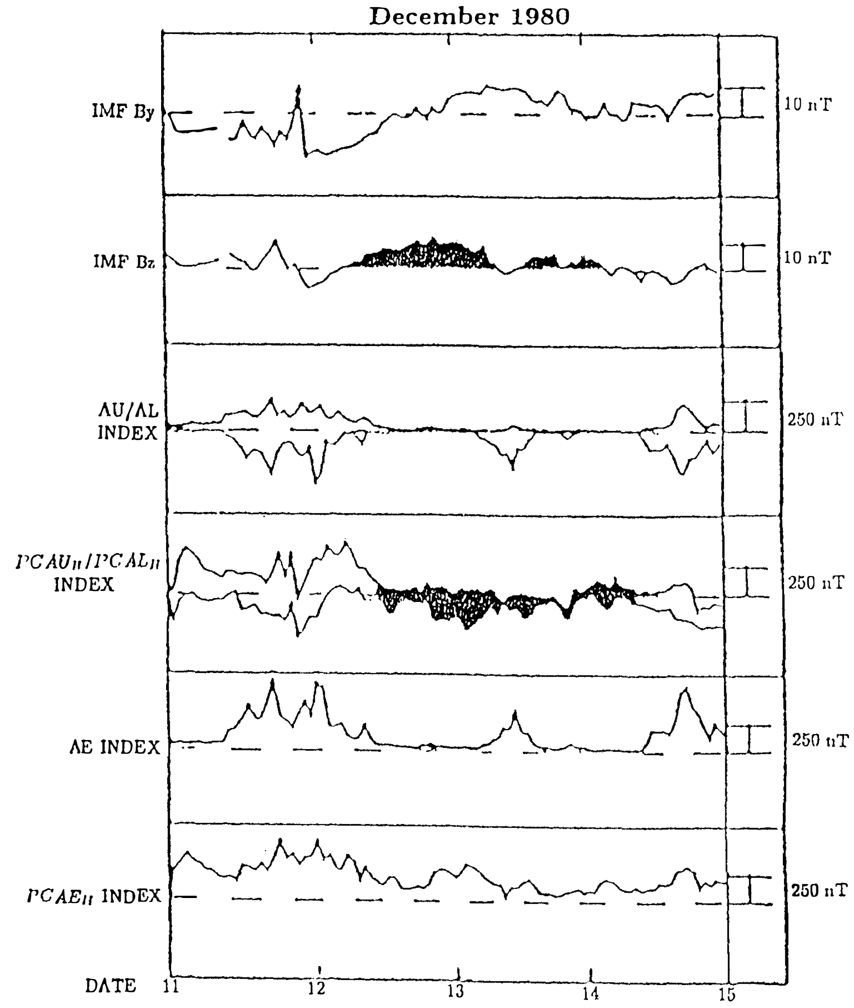


Fig. 7. ISEE 3 measurements of the IMF B_y and B_z components, compared with AU and AL, $PCAU_H$ and $PCAL_H$ indices, AE, and the $PCAE_H$ index during December 11–14, 1980.

being formed.

Figure 8 shows local time averages of the convection pattern from the four stations for different signs of B_y during summer and winter 1980. It is seen that the size of the convection vectors is dependent clearly on season, namely it is much greater in summer than in winter, while the direction of the average perturbation is different for B_y positive and negative. During winter the convection vectors is very small indicating that the perturbation almost disappears due to the low conductivity in the southern polar cap.

To demonstrate the influence of the azimuthal component B_y of IMF on the present index we show a scatter plot between the $PCAU_T$ and the IMF B_y component for the years 1966 and 1980. We found the relationship between the IMF B_y component and the $PCAU_T$ index to be quadratic especially during summer as is shown in Fig. 9. The results indicate that both signs of B_y enhance the value of the $PCAU_T$ index due to an enhancement of the B_y dependent currents in the polar cap.

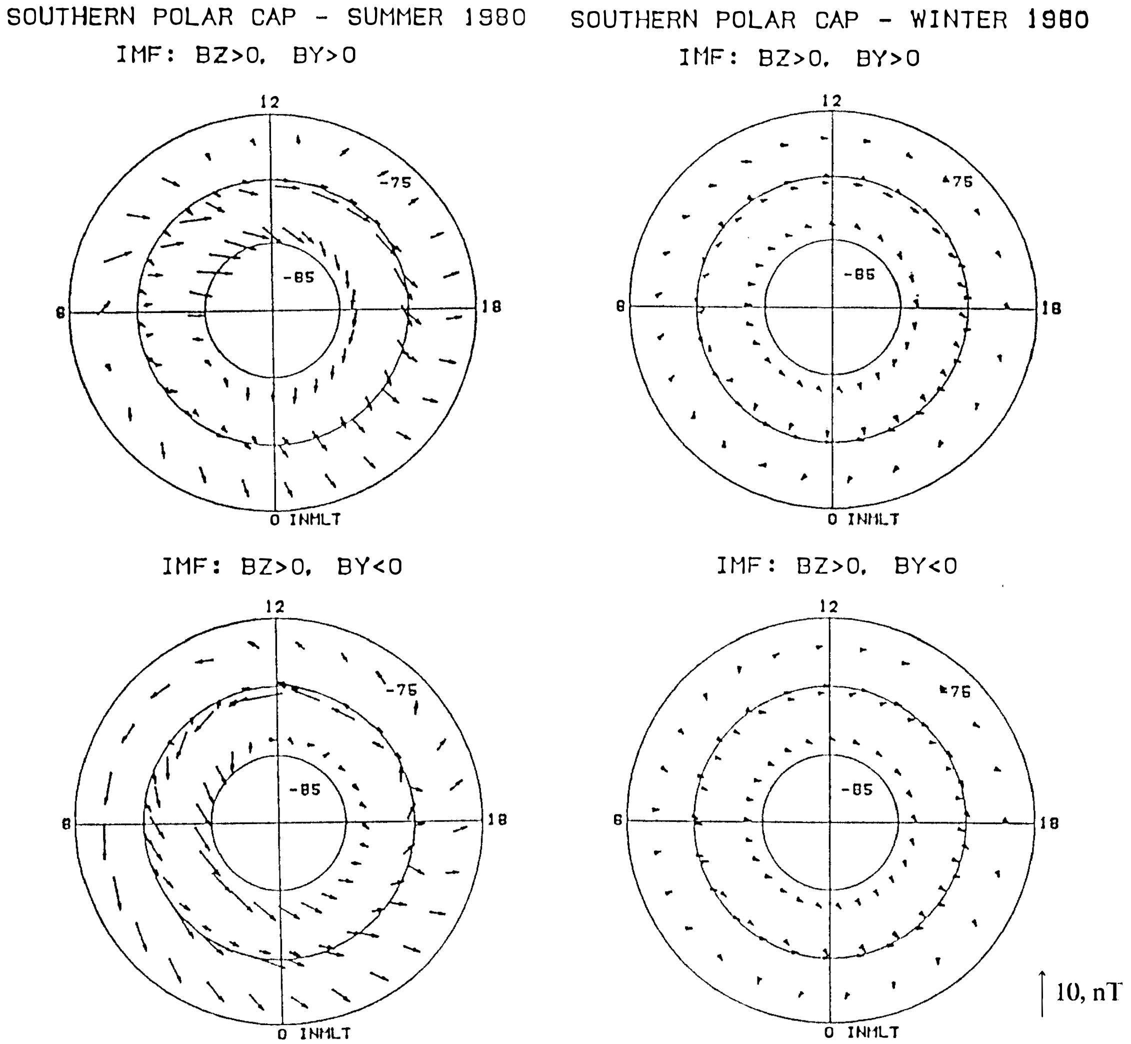


Fig. 8. *Convection pattern from the four stations in the southern polar cap for northward IMF when IMF $B_y>0$ and $B_y<0$, respectively, during local summer and winter 1980.*

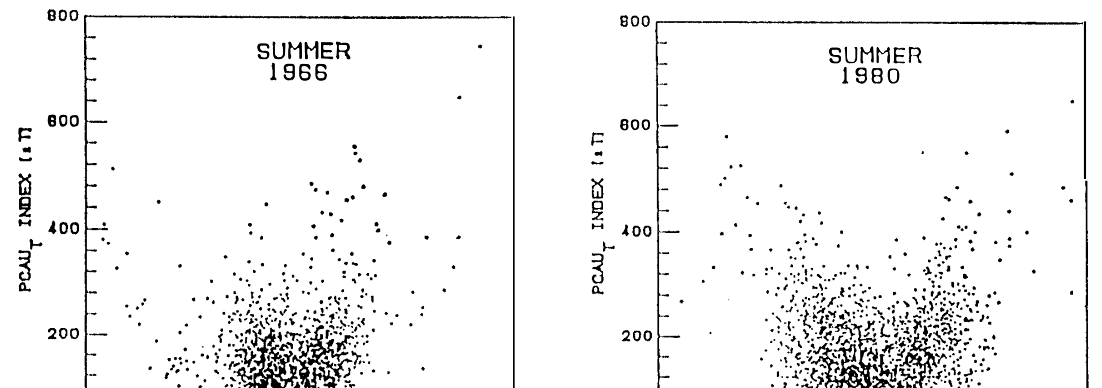


Fig. 9. *Scatter plot between the IMF B_y component and the PCAU_T index during summer 1966 and 1980.*

4. Conclusions

Ideally, the derivation of the polar cap AE index should be made using geomagnetic data from a set of stations distributed uniformly along a latitude circle in the polar cap. Although the distribution of the four stations used here is far from this ideal, we have derived on a test basis a polar cap AE index. The following conclusions were drawn:

1. The variations in the disturbance fields at the four stations for the years 1966 and 1980 show clear diurnal and seasonal variations.

2. A statistical analysis shows that the correlation between the polar cap AE index and the AE, AU, AL indices is highest in the winter season. The correlation is better with AE and AL than with AU.

3. The correlation coefficients between the polar cap AE index and the AE, AU, AL indices during solar activity maximum is greater than during solar activity minimum.

4. The correlation between the polar cap AE index and the auroral electrojet indices is better with the polar cap AE index for the *H* and *D* components than with that for the total force, *T*.

5. The relationship between the IMF B_y component and the polar cap AU index seems to be quadratic during summer.

The Automatic Geophysical Observatories which are now being planned to be set up on the Antarctic Continent would contribute substantially to the derivation of a more reliable polar cap index than was obtained here on a test basis using existing stations.

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