Thirteenth Indian Expedition to Antarctica. Scientific Report, 1997
Department of Ocean Development, Technical Publication No. 11, pp. 91-105

Movement of Indian Antarctic Station Maitri into Auroral Oval during Geomagnetic Disturbance

S. BANOLA, AJAY DHAR and GIRIJA RAJARAM

Indian Institute of Geomagnetism, Colaba, Bombay 400 005

Abstract

During the 13th Summer Indian Antarctic Expedition (Dec 1993 - March 1994), fluxgate magnetometers were operated at the Indian Antarctic locations MAITRI (MAI) and DAKSHIN GANGOTRI (DG). The variations of the X, Y, Z geomagnetic components when compared between magnetically Quiet days, moderately Disturbed days, and clearly Disturbed days, indicate that during quiet times, the Indian stations occupy a sub-auroral position; with increasing disturbance, they come into the auroral oval, and then the geomagnetic variations bear the signature of the auroral electrojet (AE) and field-aligned currents (FAC).

Ionospheric horizontal current densities in the north-south and east-west directions are estimated from the variations in the geomagnetic components using the Biot-Savart law. They indicate that the current densities over MAI and DG increase with increasing electromagnetic disturbance in geospace, more sharply in the Dawn sector than in the Dusk sector.

Introduction

The auroral ovals in the northern and southern hemispheres constitute those regions of Earth which map along geomagnetic field lines to the plasmasheet region of the magnetosphere. In other words the regions of Earth between 65° - 75° latitude map to the volume of geospace between geomagnetic shells of 4 Re and over 100 Re (1 Re = Earth radius = 6370 km) (Fig. 1). The auroral ovals thus constitute oval-shaped regions around the geomagnetic poles, but they are asymmetric with respect to the poles i.e. at higher latitudes on the dayside, lower latitudes on the nightside (Fig.2a). With increasing electromagnetic disturbance in geospace, the action in the magnetosphere moves earthwards, the plasmasheet moves earthwards and hence maps to lower latitudes, and then the auroral oval moves to lower latitudes (as low as 55° - 65°) (Fig.2b).

The Indian Antarctic station MAITRI (MAI at geog. lat. 70° 46"S long 11°45'E) appears to have a unique location just equatorwards of the quiet-time

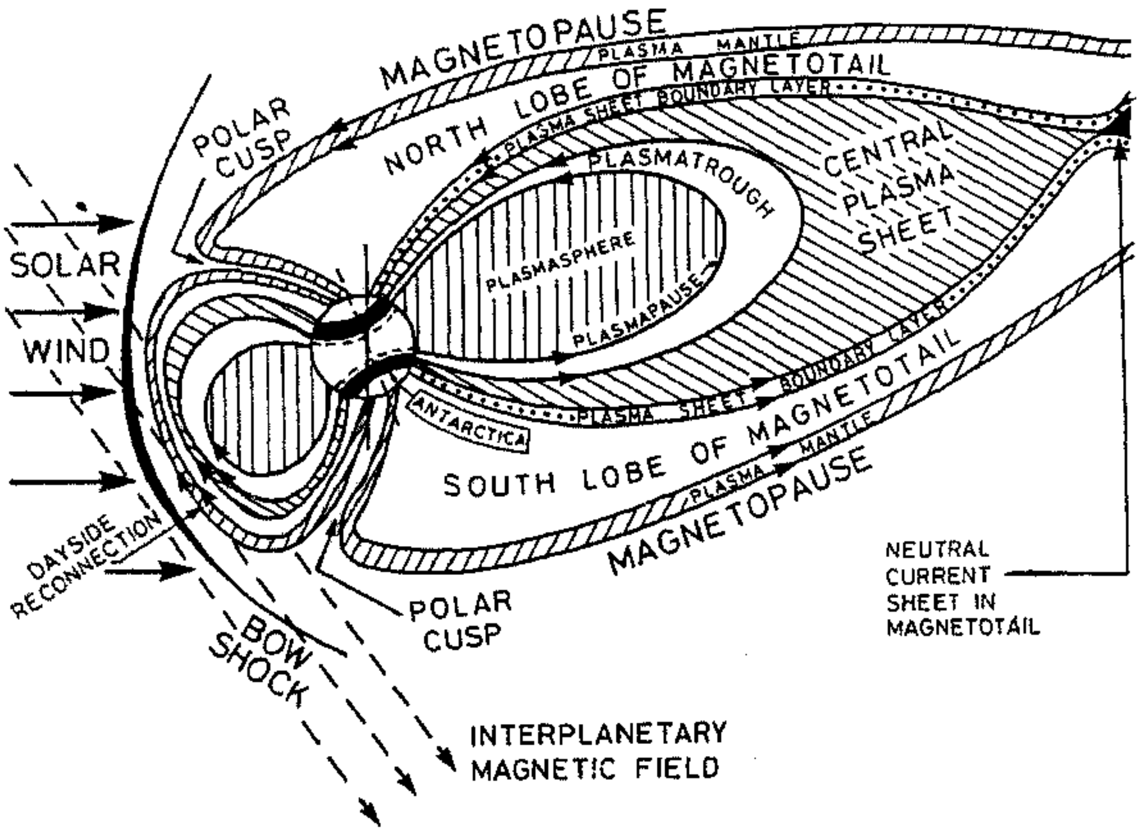


Fig. 1: Polar cross-section of Earth's magnetosphere as viewed from a point an space in the duskside. The Central Plasma sheet region of the magnetosphere maps into the auroral regions of the Earth

auroral oval i.e. it lies just outside the auroral oval during magnetically quiet times, and comes into the auroral oval during magnetic disturbance. This implies that during quiet times, the geomagnetic signatures at MAI are mainly that of the Sq (solar quiet) currents which flow in the low and mid-latitude ionosphere. In contrast during Disturbed times, it is the auroral currents which affect the geomagnetic field monitored at MAI. These aspects are demonstrated in this work, using the variations of the Y, X and Z orthogonal components of the geomagnetic field recorded at MAI during Jan 1994. Using the Biot-Savart law which expresses the relationship between a finite line current and the magnetic deflection which it causes, the increase in ionospheric current intensity over MAI with increasing electromagnetic disturbance in geospace is shown in this work.

Experimental Set-up

Experimental set up is shown in Fig. 3. During 13th Antarctic Summer (Jan 1994) fluxgate magnetometers were operated at two locations MAITRI and

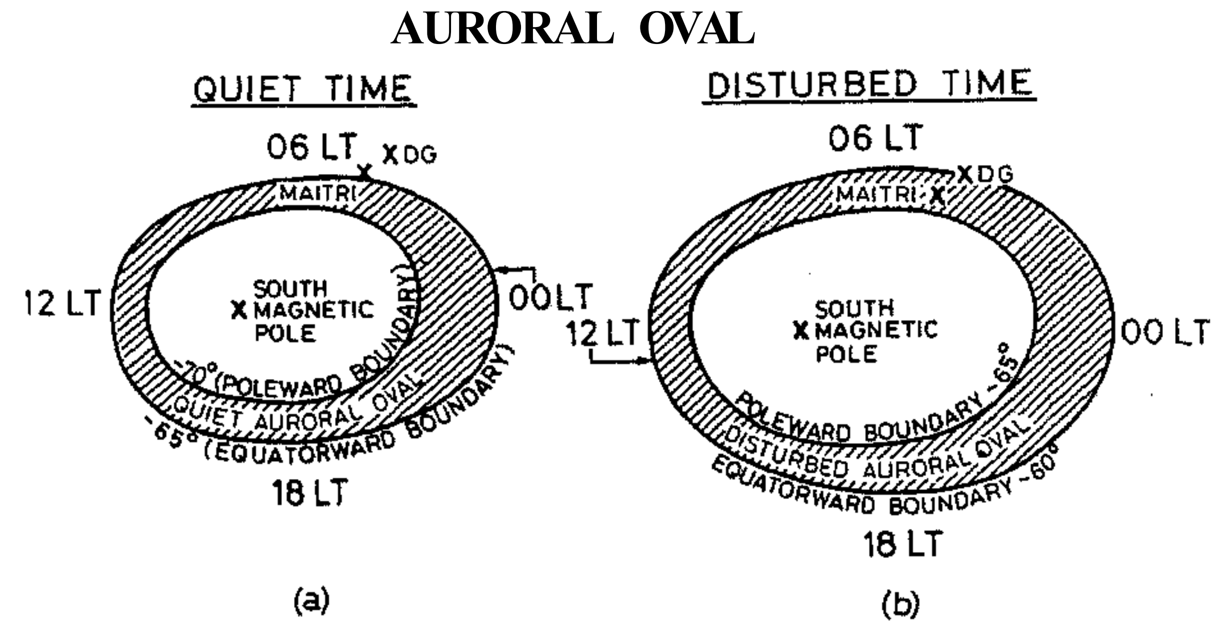


Fig.2: The auroral oval during magnetically quiet times usually lies between 65° and 70° latitudes. At is always a little broader and more pulled away from the magnetic pole towards the nightside. At such times, the Indian Antarctic station, Maitri & DG lie just equatorwards of the auroral oval as shown in Fig. 2(a). During magnetic disturbance, both the stations move into the auroral oval as shown in Fig. 2(b). The auroral oval occupies the latitudinal region 60-65° because of moves equatorward during disturbances

DAKSHIN GANGOTRI (DG Camp operated from 12- 27 Jan 1994). Daily Variation (DV) records were recorded in digital form whereas Micropulsation (MP) data were recorded in analog and digital forms. The DV records were obtained on normal chart speed of 3 cm/hr. MP data was obtained on similar chart recorders at a rapid run of 12 cm/hr after retaining all pulsations with time-period between 30 sec and 3000 sec i.e. with frequencies between 0.33 mHz and 33 mHz.

Observations

Changes in X, Y, Z components with increasing magnetic disturbance

Fig. 4 shows the response of X (north-south) magnetic field component at MAI to increasing disturbance in the geospace environment. On Quiet days (first block of Fig.4), the daily variation of X is negative, minimising around noon. This is possibly the signature of westward-directed Sq current system (discussed in Sec. 4) which MAI sees in the daytime. On moderately disturbed days a negative trend in the dawn hours and a positive trend in the dusk hours

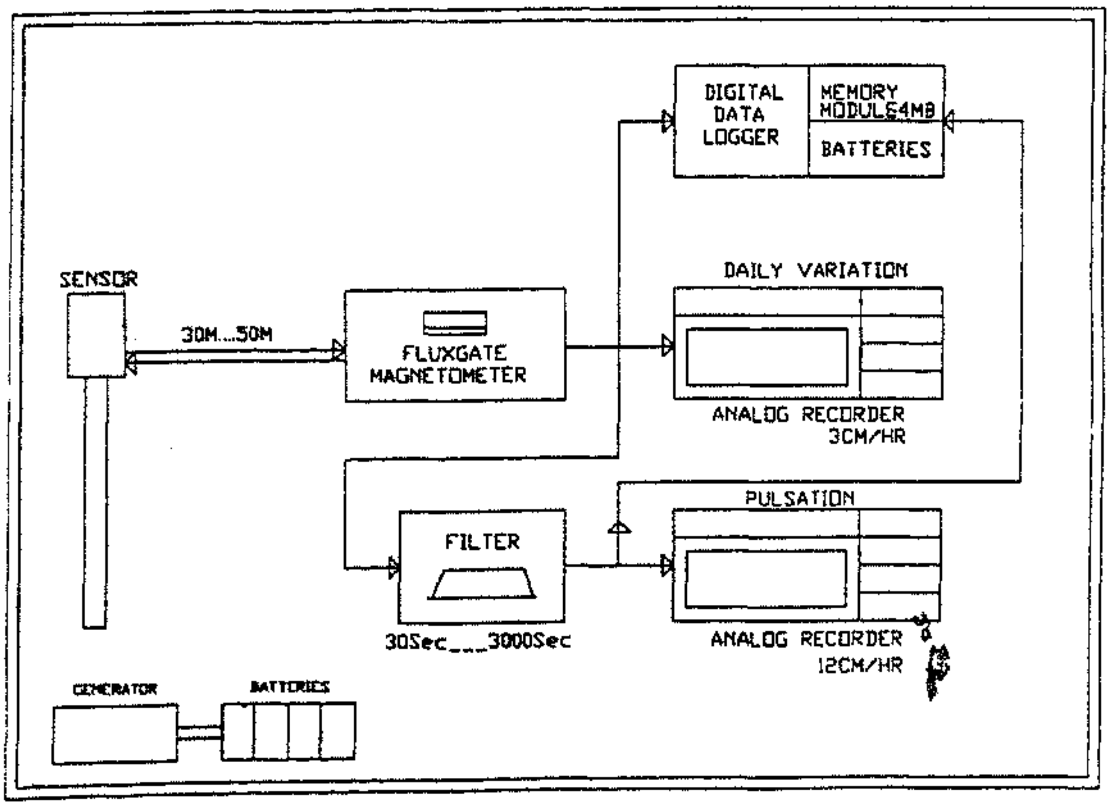


Fig3: Block diagram of Fluxgate Magnetometer set-up used to record daily variations and pulsations in the X,Y& Z components of the geomagnetic field at Maitri & Dakshin Gangotri

starts showing up (second block of Fig.4). These become very prominent for clearly Disturbed conditions (third block of Fig. 4). The southward magnetic field of the Dawn hours is a typical auroral signature of the dawnside Westward Auroral Electrojet (WAE) while northward magnetic field in the dusk hours is the signature of the duskside Eastward Auroral Electrojet (EAE). Thus MAI during disturbed conditions evidently comes into the auroral oval, and experiences WAE and EAE currents.

Fig. 5 shows the response of Y (east-west) geomagnetic field component at MAI. There is a negative (westward) signature during pre-noon hours. This would be due to the northward limb of the. Sq current in the southern hemisphere. Positive (eastward) signature in Y during post-noon hours would be due to the southward limb of the Sq current. Fig. 5 also shows that with increasing disturbance, peaks occur in the dawn hours and weak peaks in the dusk hours (second block of Fig. 5). These features increase in intensity on clearly Disturbed days (third block of Fig. 5), The geomagnetic variations on Disturbed days at MAI are typical auroral signatures of field-aligned currents (fac) which flow between magnetosphere and ionosphere.

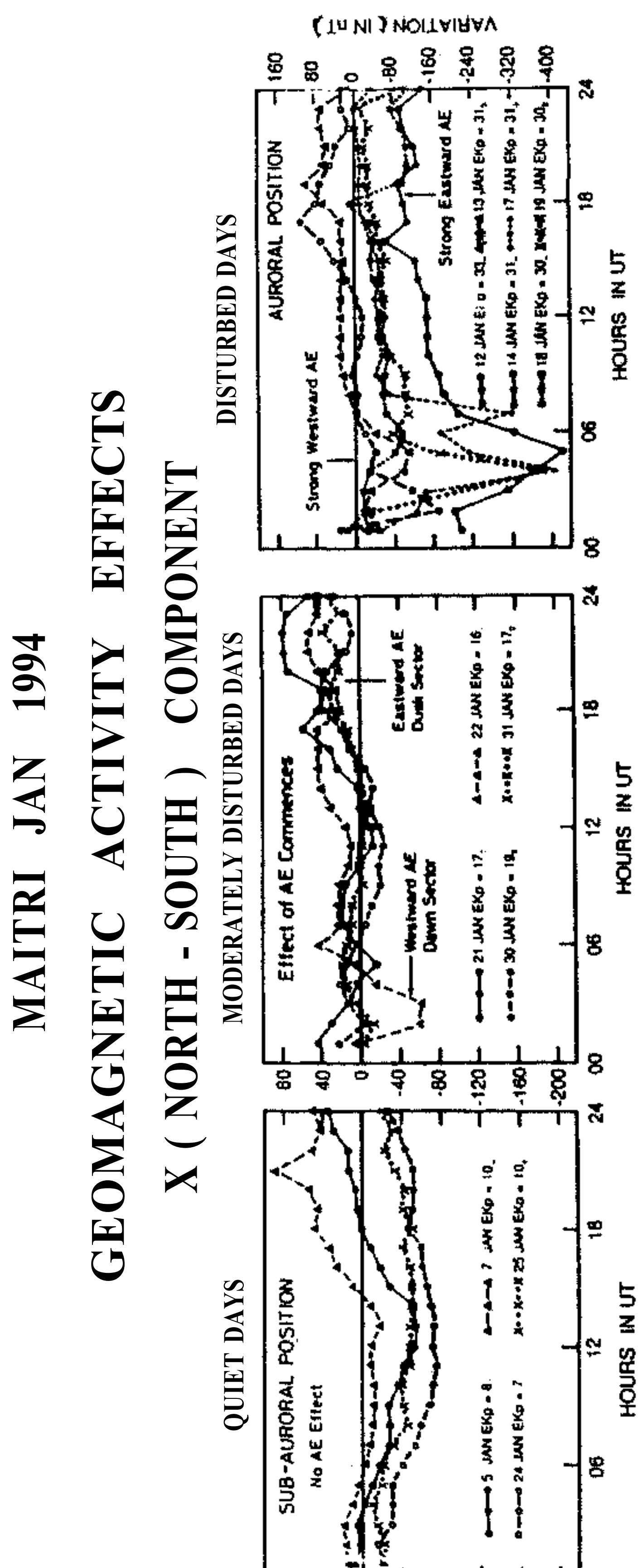


Fig.4: Response of the X (North-South) geomagnetic field component at Maitri to increasing disturbance in the geospace environment. Note how the variations show Sq influence during Quiet times and AE influence during Disturbed times

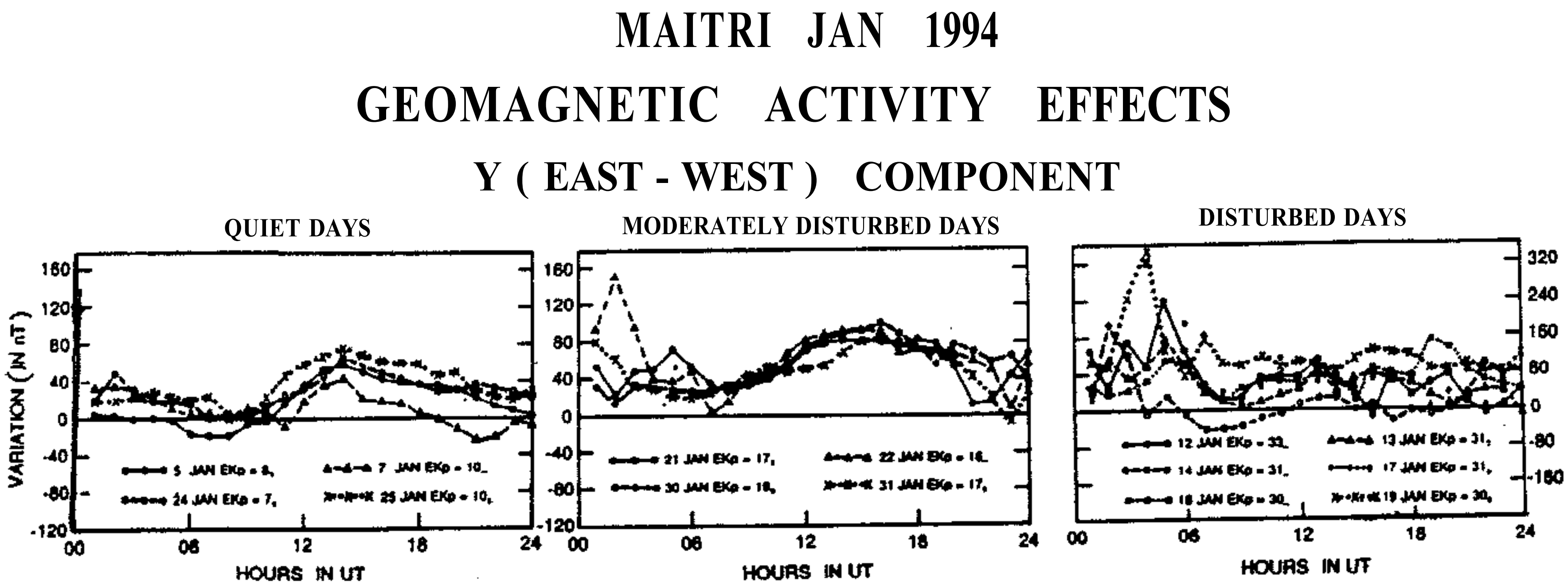


Fig.5: Response of the Y(East-West) magnetic field component at Maitri to increasing disturbance in the geospace environment. Note how the Sq current influences Y on Quiet days, and the effect offac shows up on Disturbed days

Fig. 6 shows Z (vertical) component of magnetic variation. On Quiet days, predominantly negative (upward) signature is seen in the daytime. This is expected if MAI is located poleward of the westward limb of the daytime southern Sq current loop. With the onset of disturbance a negative signature starts showing up in the dawn hours, and a positive Z is seen in the dusk hours (second block of Fig. 6). On Disturbed days, clear negative signature in Z in the post-midnight hours and positive signature in pre-midnight hours is seen (third block of Fig. 6). This would show Maitri rotating under the Harang Discontinuity (HD) (discussed in Section 4), with a rather equatorward position in the auroral oval. MAI thus sees the positive Z signature of the EAE in the pre-midnight hours and a negative Z signature of WAE during post-midnight hours.

Calculation of Auroral Electrojet Current Density over Maitri

An estimate of current densities in the ionosphere over Maitri is made from the Biot-Savart Law, following Kamide and Akasofu (1974). A horizontal current configuration is assumed to flow in the ionosphere over MAI, although strictly speaking this is not correct and field-aligned currents (fac) are also present on Disturbed days. Horizontal current densities in the north-south (X) direction and east-west (Y) directions are given by

$$i_x \text{ (amp/km)} = K\frac{10}{2\pi}\Delta Y_m \text{ (nano Tesla)}$$

$$i_y \text{ (amp/km)} = K\frac{10}{2\pi}\Delta X_m \text{ (nano Tesla)}$$

where $k = \frac{2}{3}$ is a correction factor for current induced within Earth

ΔY_m is range in Y component

ΔX_m is range in X component

Ranges in X & Y are taken separately for the pre-noon and afternoon hours, and the current densities i_x & iy are estimated separately for the Dawn and Dusk Sectors.

Fig. 7 and Fig- 8 show the horizontal current densities i_x (north-south) and i_y (east-west) respectively in the Dawn sector. A clearly rising trend is seen in the values of the current calculated for various days, as disturbance increases.

The rising trend is seen despite great scatter in the points, markedly on highly disturbed days. This scatter merely indicates the great day-to-day variability in the auroral ionosphere, especially during disturbed periods sug-

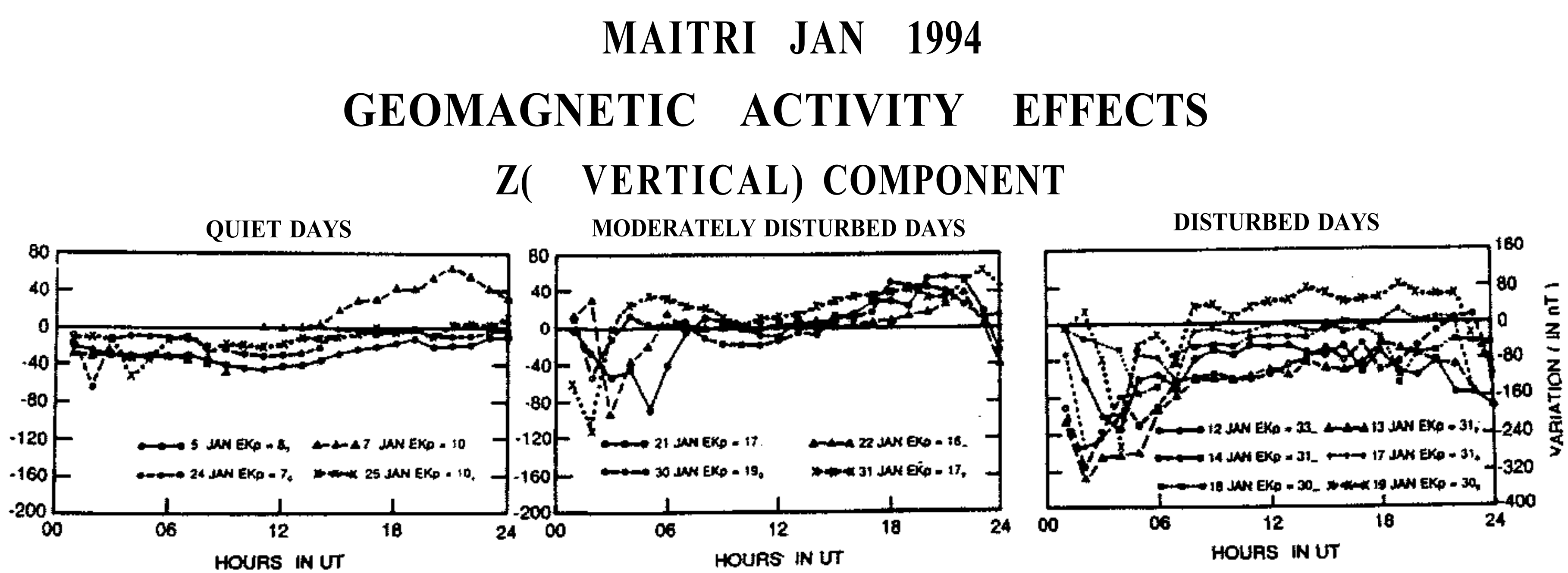


Fig.6: Response of Z (Vertical) magnetic field component at Maitri to increasing disturbance in the geospace environment. The Quiet time signature is that of Sq currents while the Disturbed days show transit under the midnight Harang Discontinuity

IONOSPHERIC CURRENT DENSITY i_x (NORTH-SOUTH)
MAITRI-JAN 1994
DAWN SECTOR
WESTWARD AURORAL ELECTRO JET
OVER MAITRI DURING DISTURBED DAYS

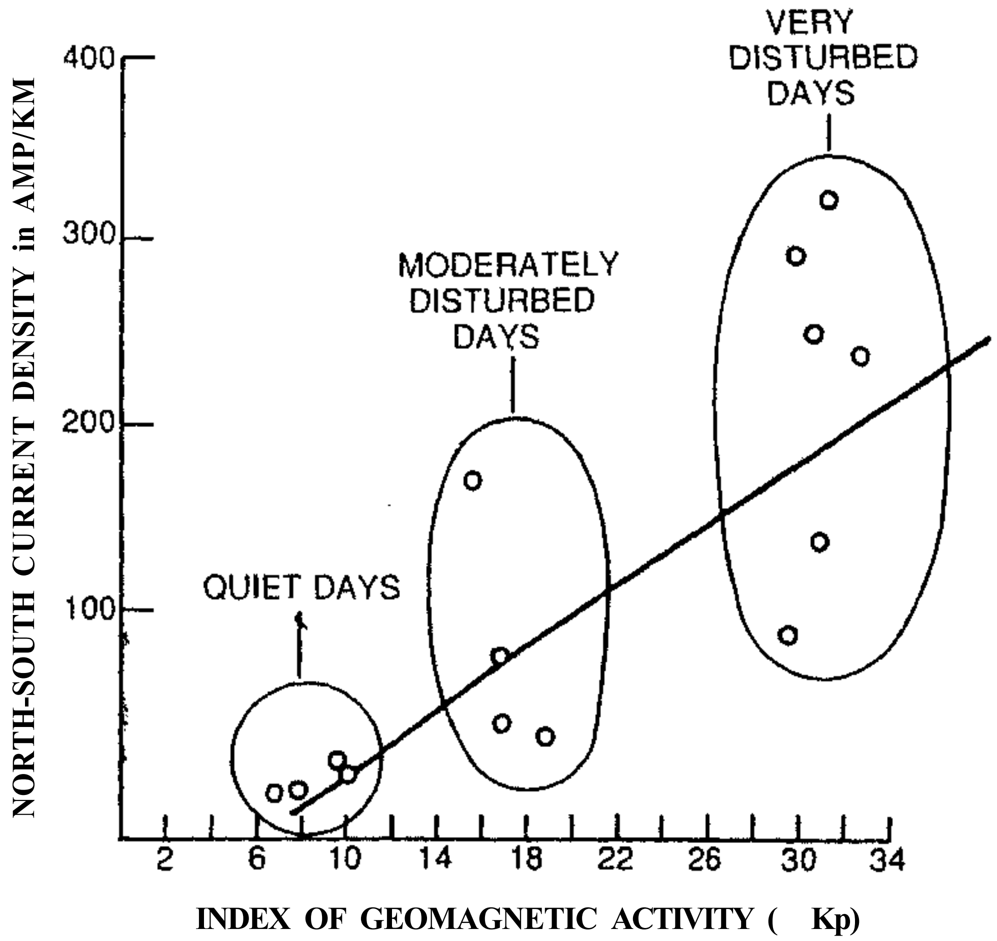


Fig.7: Variation of North-South Ionospheric Current Density i_x (in amp/Km) with index of Geomagnetic Activity (kp)for Dawn Sector at Maitri during January 1994

gesting that one disturbed day can be very different from another because of highly varying electromagnetic conditions in the distant magnetosphere and in the ionosphere. Further k_p is an average index and conditions over a given site in the auroral region can be significantly differ for the same value of k_p. Part of this variables could also be attributed to the relative role of field aligned currents.

Fig. 9 and Fig. 10 show i_x (north-south) and i_y (east-west) horizontal .ionospheric current densities in the Dusk sector. It is clear that the change in current density with magnetic disturbance in the Dusk sector is much smaller than in the Dawn sector (cf. Fig. 7 and Fig. 8), and the scatter of points is also

IONOSPHERIC CURRENT DENSITY i_y (EAST-WEST)
MAITRI-JAN 1994
DAWN SECTOR
WESTWARD AURORAL ELECTROJET
OVER MAITRI DURING DISTURBED DAYS

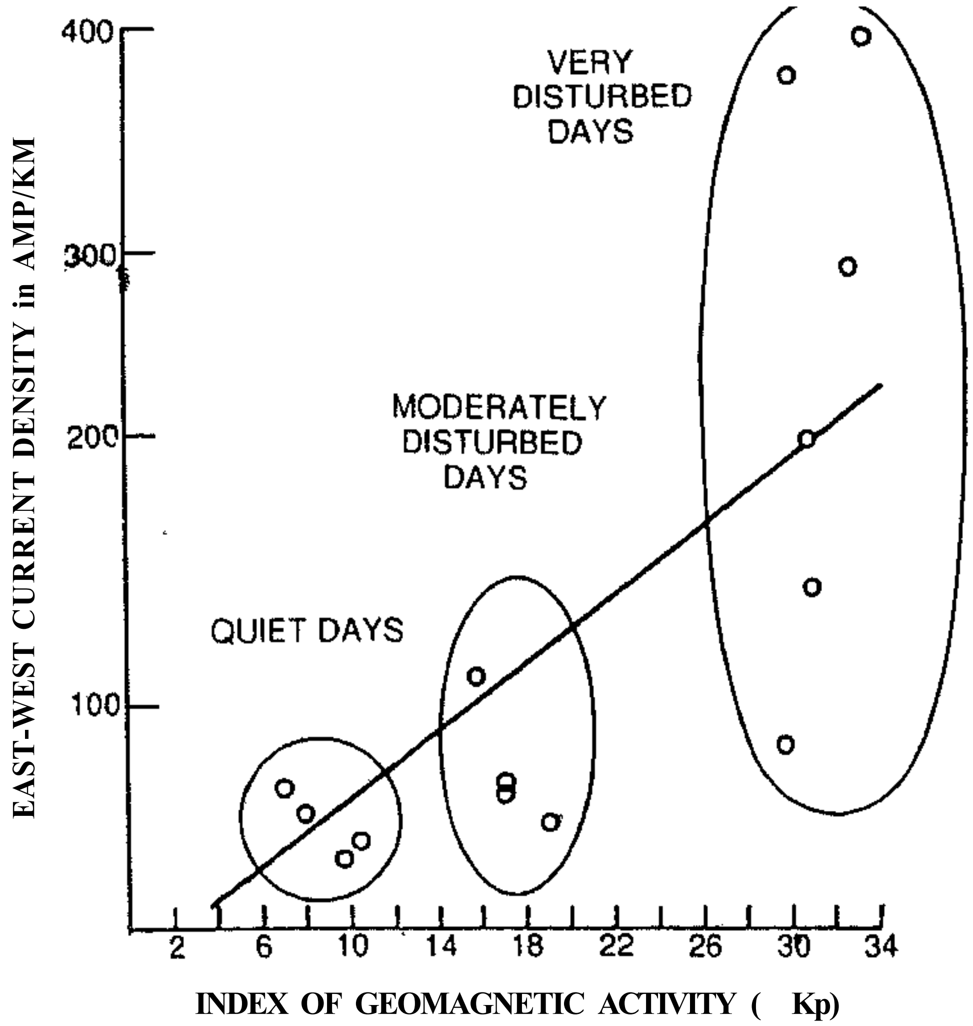


Fig.8: Variation of East-West Ionospheric Current Density i_y (in amp/Km) with index of Geomagnetic Activity (k_p) for Dawn Sector at Maitri during January 1994

less for the Dusk sector. While current densities in the Dawn sector range from 30-300 amp/km, values vary over 30-130 amp/km in the Dusk sector.

Conclusions and Discussion

Geomagnetic observations at high latitudes, markedly in the auroral regions, have a special value, because they provide a clue to electromagnetic processes at work in deep, distant geospace (upto 100 Re and beyond). This is

IONOSPHERIC CURRENT DENSITY i_x (NORTH-SOUTH)
MAITRI—JAN 1994
DUSK SECTOR
EASTWARD AURORAL ELECTROJET
OVER MAITRI DURING DISTURBED DAYS

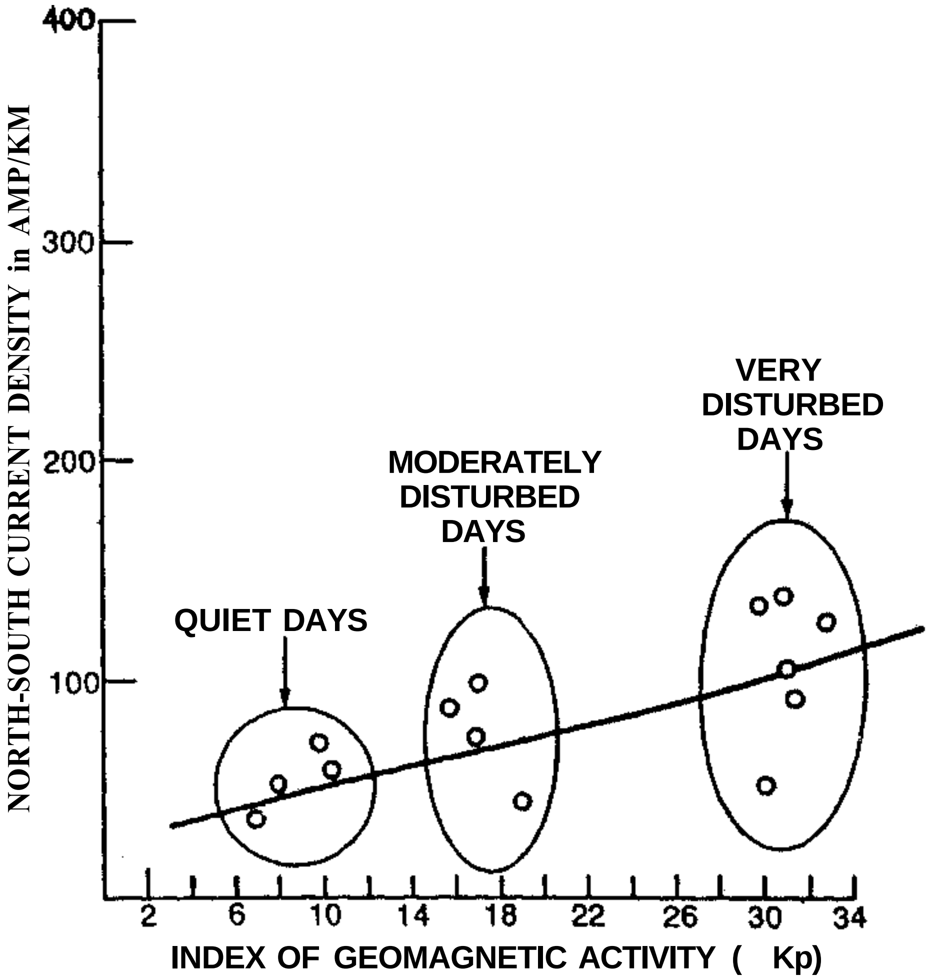
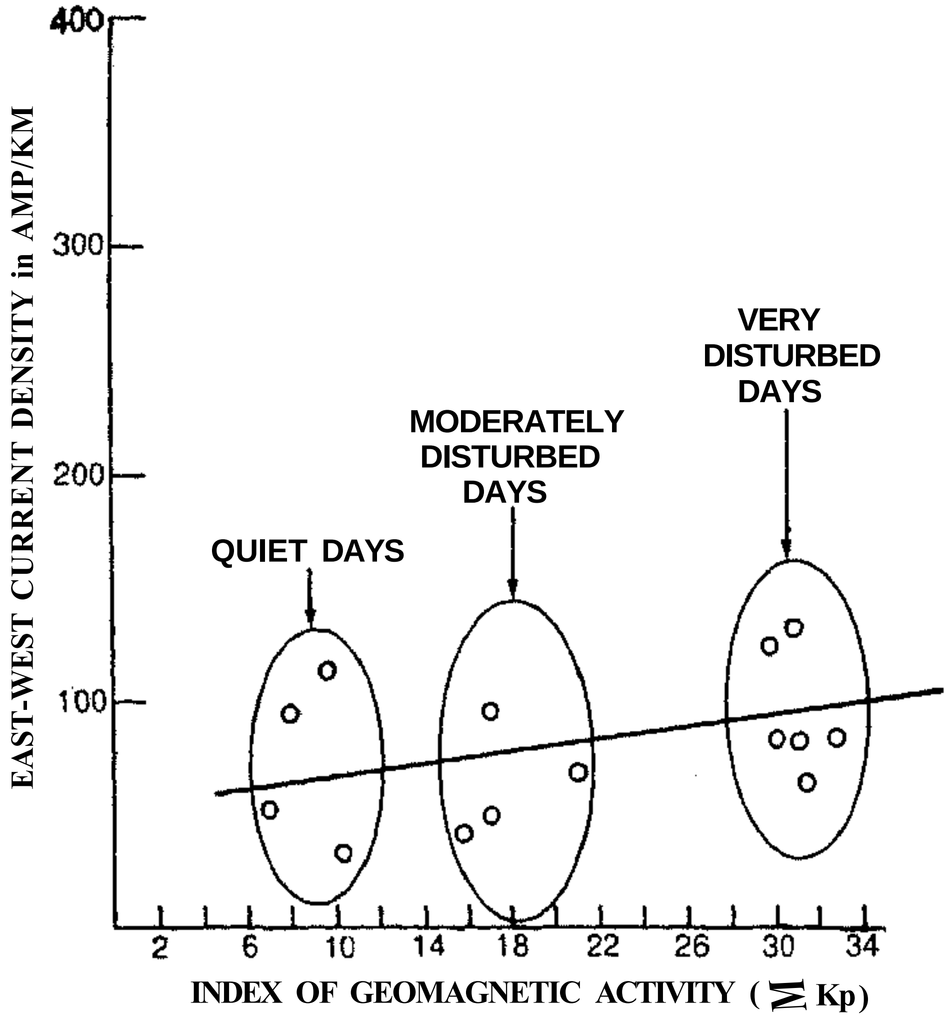


Fig. *9: Variation of North-South Ionospheric Current Density* i_x fin *amp/Km) with index of Geomagnetic Activity (Kp)for Dusk Sector at Maitri during January 1994*

because the geomagnetic field lines which are rooted at these latitudes are stretched out to great distances in the geomagnetosphere by the action of the solar wind (Parker 1958). The field lines act as good electrical conductors, and electric and magnetic fields are mapped from the magnetosphere into the auroral ionosphere. The auroral lights ('auroral borealis' in the northern hemisphere and 'auroral australis' in the southern hemisphere) are a direct, visible evidence of those mapping processes, subsequent to the entry of solar wind into the geomagnetosphere.

In this work we observe the following:-

IONOSPHERIC CURRENT DENSITY i_y (EAST-WEST)
MAITRI-JAN 1994
DUSK SECTOR
EASTWARD AURORAL ELECTROJET
OVER MAITRI DURING' DISTURBED DAYS



Frg, 10: *Variation of East-West Ionospheric Current Density i_y (in amp/Km) with index of Geomagnetic Activity (k_p)for Dusk Sector at Maitri during January 1994*

1. The changes in X, Y & Z geomagnetic components clearly show that Maitri is located in a sub-auroral zone during magnetically Quiet times and comes directly into the auroral oval during magnetically Disturbed times. MAI registers the geomagnetic signatures of the eastward and westward auroral electrojet currents. On magnetically disturbed days the Z component registers the signature of the Harang Discontinuity at midnight changing from negative to positive.

2. The north-south and east-west horizontal current densities over MAI increase with increasing magnetic disturbance, in both Dawn and Dusk time

sectors. While current densities in the Dawn sector range over 30-300 amp/km, those in the Dusk sector are only 30-130 amp/km.

3. Variability of current densities i.e. scatter of points increases with increasing magnetic disturbance, and is more in the Dawn sector than in the Dusk sector.

The last two points indicate that the more energetic plasma processes occur in the Dawn sector (Heppner 1954), with a great deal of day-to-day variability. This aspect requires more investigation, and we do not elaborate on the causes in this work.

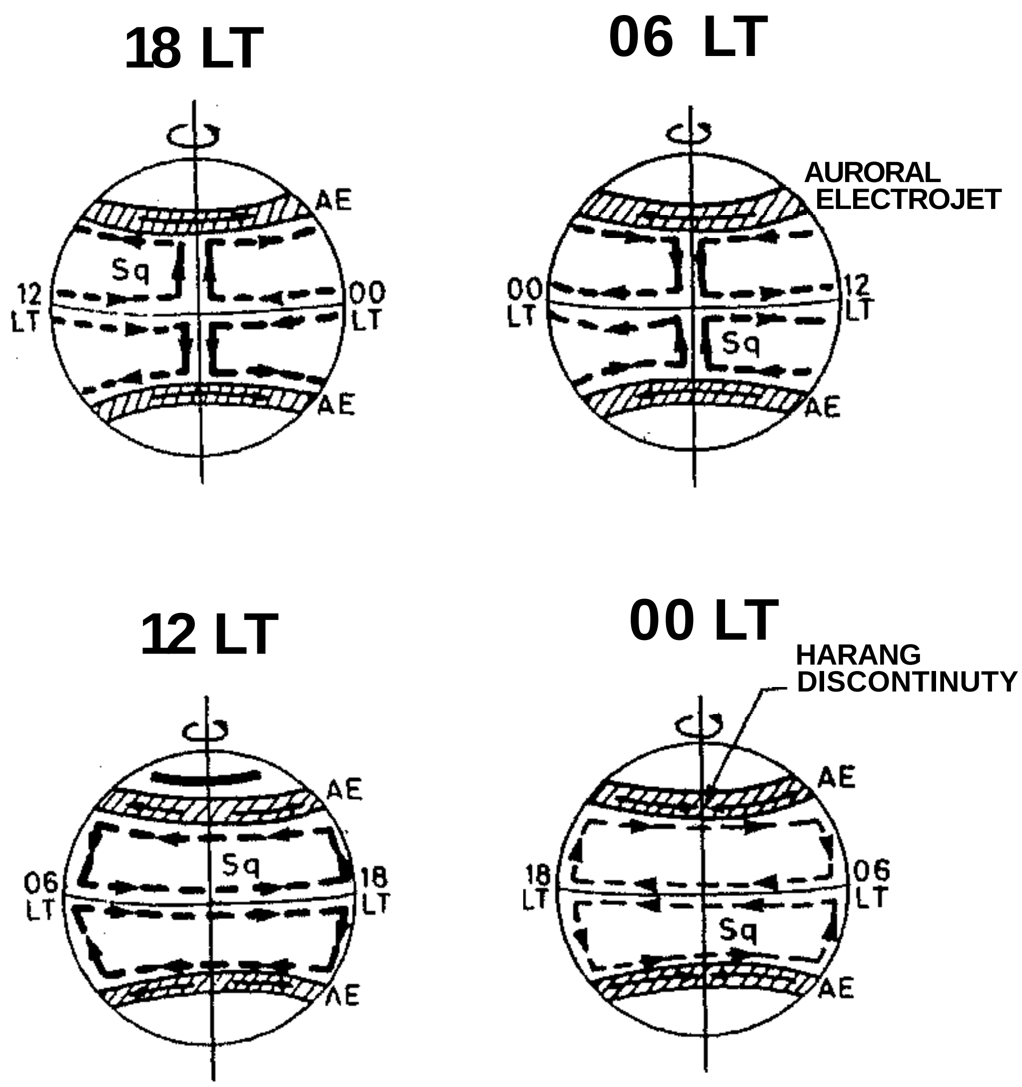


Fig.11: Current systems influencing high latitude quiet times

Two other points need elaboration. In Section 3.1, it was mentioned that the X component in Fig. 4, and the Z component in Fig. 6, during magnetically Quiet times bear the signature of the westward limb of Sq current in the southern hemisphere. This Sq current system is shown in Fig. 11, along with the auroral electrojet (AE) current systems at the higher latitudes. If one focuses on the view for 12 LT, one will realise that a station which lies equatorward of the southern auroral zone, will see the Sq current signatures with negative X component and a negative Z component in the noon hours. This is what is seen by MAI at Quiet times, and hence the conclusion that MAI is sub-auroral during magnetic Quiet. During magnetically Disturbed times MAI moves into the auroral zone, and then it records the typical signatures of the eastward auroral electrojet (EAE) [18 LT in Fig..l 1] in the afternoon hours, and the westward auroral electrojet (WAE) [06 LT in Fig. 11J in the morning hours.

The Harang Discontinuity (HD, cf. Kamide and Baumajohann 1993), referred to while discussing the Z variations in Fig. 6 is indicated in Fig. 11. In this figure, the label is marked against the northern auroral zone, but a similar feature exists in the southern auroral zone as well. The HD basically is a region in the midnight sector where the EAE of the Duskside changes over to WAE of the Dawnside. Continuity is maintaixiedh*%qugh field-aligned currents (FAC), and these FAC intensify grttftifyduring magnetic disturbance. It is this change-over from EAE to WAE that the Z component at MAI (Fig. 6) registers, when the station comes under Jjle JiD feature during magnetic disturbance.

Finally a word about the estimation of the current densities i^, i_y in Fig. 7, 8, 9 and 10. These are done ol the basis of the Biot-Savart law, assuming only horizontal line currents in the iolosphere. FAC have been ignored, and the contribution of these to geomagnetic variations at auroral latitude's is considerable, notably during magnetic d^uffiapce. The eontributions from FAC and AE have to be separated, and work is being attempted in this direction.

Acknowledgements

The authors are grateful to D.O.D., Government of India, for providing travel facilities to Antarctica, and full logistic support at Antarctica, to enable participating organisations to carry out scientific experimentation. They are grateful to the Indian Institute of Geomagnetism, Bombay, for full encouragement towards geomagnetic studies at Antarctica.

References

KAMIDE Y. and-S-I AKASOFU (1974), 'Latitudinal cross-section of the auroral electrojet and its relationship to the interplanetary magnetic field polarity', J. Geophys. Res., 79, 3755-3771.

KAMIDE Y. and W. BAUMJOHANN (1993) 'Magnetosphere-Ionosphere Coupling' p. 20, Pub. Springer-Verlag, Berlin, Heidelberg, N.Y.

PARKER E.N. (1958), Interaction of the solar wind with the geomagnetic field, Phys. Fluids, 1,171-187.

HEPPNER J.P. (1954), Time sequences and spatial relations in auroral activity during magnetic bays at College, Alaska, J. Geophys. Res. 59, 329-338.