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THREE-STATION MAGNETOMETER EXPERIMENT AT ANTARCTICA DURING JAN-1996 TO DETERMINE THE VELOCITY OF . DISTURBED-TIME OVERHEAD AURORAL CURRENT SYSTEMS

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Abstract

Three fluxgate magnetometers were operated simultaneously at the Antarctic locations Maitri (70°45' S lat., 1 l°45'Elong.), Dakshin Gangotri (70°08' S lat., 12°Elong.) and Orvin Mountains (71°56.20' S lat., 08°45.79' E long.) in Jan 1996. The three stations form the vertices of a triangle with sides ranging from 76 km to 233 km. Using appropriate electronic filters to retain pulsation's with periods between 30 sec (f = 33 MHz) and 3000 sec (f = 0.33 MHz), pulsations in X, Y and Z components of the geomagnetic field were recorded. Pulsations during disturbed conditions are interpreted in terms of the mobile auroral current systems which drift over the stations and leave signatures in ground based magnetometers. From the time-lags in similar pulsations at the three stations, the drift velocities of the overhead small-scale ionospheric current systems are estimated. The values during Jan 1996 are found to lie between 0.94 km/sec and 3.44 km/sec, and these tally well with observations of 0.6 to 2 km/sec made for the northern auroral hemisphere.

Introduction

India operates a permanent station Maitri (MAI) at Antarctica in the Schirmacher Oasis, round the year. In addition, two summer stations were operated at Dakshin Gangotri (DG) and Orvin Mountains (OR). The geomagnetic co-ordinates calculated from the IGRF 1995model for these three stations are MAI (66°53' S, 56°42' E), AE (66°22' S, 57°36' E) and OR (67° 42 ' S, 52°65 'E). DG Station is on the Queen Maud Land ice-shelf at a distance of 76 km from MAI, whereas OR is situated to the west of the Wohlthat mountain range at a distance of 233 km from MAI (see **Fig.l** for an area of the topography). The three stations were operated simultaneously from 16 Jan 1996, and were expected to run for about a month. OR camp recording however had to be stopped on 31 Jan, when following a very severe blizzard with wind

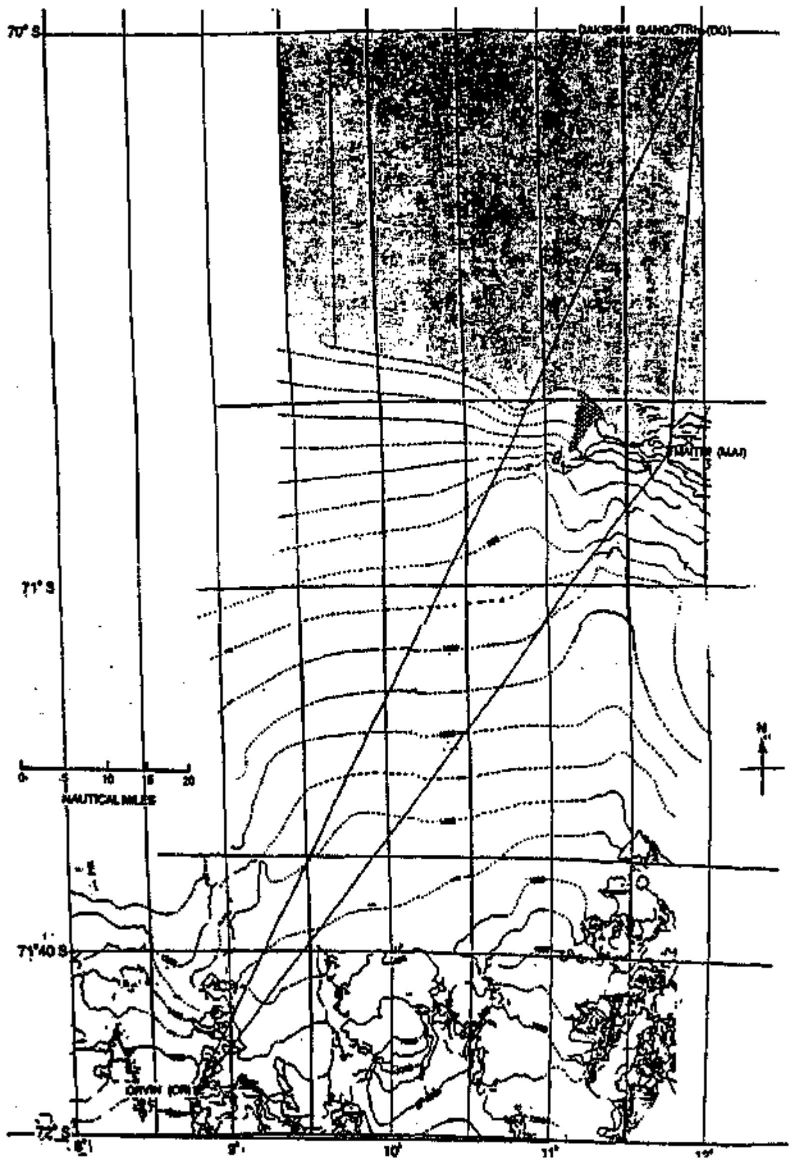


Fig. I: Contour map of the area showing the three locations Maitri (MAI), Dakshin Gangotri (DG) and Orvin Mountains (OR), where three fluxgate magnetometers were simultaneously operated over Jan 16-31, 1996. It may be noticed that OR lies in the deep interior mountains where high wind speeds during blizzards created very difficult operating conditions.

speeds of more than 150 km/hr, two of the three MFC type tents used for housing the members and the instruments, were torn and damaged. One of the tents was blown to more than 50 m along with its two occupants. The five members at the camp had to take refuge in the lone, surviving, partially-damaged tent, and hold on to its sides and corners to prevent it from collapsing. Temperatures of -30°C were recorded at the OR camp and the instruments had to be covered with thermally insulated sleeping-bags to keep them functioning at such low temperatures. In spite of all these measures taken, there were still several days when recording at one or the other of the three stations was disrupted for various reasons. Two examples are rapid draining of batteries under sub-zero temperatures, and mechanical problems with the analog recorders, again because of very low temperatures.

Regular monitoring of the geomagnetic field and magnetic pulsations have been carried out at MAI station by IIG (Indian Institute of Geomagnetism) since 1991. Daily variation (DV) and magnetic pulsations (MP), are recorded in analog and digital modes using a fluxgate magnetometer. MAI during quiet magnetic conditions lies equatorward of the auroral electroject current system, and experiences the effect of the southern limp of the southern hemisphere Sq current system. With increasing magnetic activity, the auroral electroject current system moves equatorwards and MAI starts recording the magnetic signatures of auroral electroject currents as well as field-aligned currents, and other mobile current systems associated with substorms (Hanchinal *et al.* 1995, Banola and Rajaram, 1996). This would also be true of DG and OR stations due to their proximity to MAI. With increasing disturbance, OR station then should enter the auroral oval first followed by MAI and then by DG stations.

The field-aligned currents (fac) discussed above should cause sharp changes in the amplitudes of the X and Y components, and this indeed was observed in the data. Since the fac are caused by energetic electrons precipitating from the magnetosphere, they are subject to E x B drift in the auroral ionosphere. They drift in the geomagnetic east-west direction and give rise to localised small-scale current vortices. The velocities of these mobile current systems can be calculated from an array of magnetometers in the east-west and north-south directions, as has been successfully shown for the northern auroral zone by Kisabeth and Rostoker (1973), Akasofu (1974), Andre and Baumjohann (1982) and Opgenoorth *et al.* (1983). Operating such arrays in the harsh climate and difficult terrain of Antarctica is very difficult for various logistic reasons. We have been able to operate 3 magnetometers several times in Antarctica at the vertices of a triangular area, to estimate the drift speed of mobile overhead current systems over and around MAI. Similar experiments were carried out in Jan 1992 and Jan 1995, and the velocity of current systems moving over MAI were estimated (Rajaram *et al.* 1995, Rajesh Kalra *et al.* 1996). The distances between the stations should ideally be 100-200 km keeping in mind the scale-size of these current systems. We were able to achieve this for the DG-OR and MAI-OR pairs, but the DG-MAI distance is only around 76 km.

Long-period pulsations in geomagnetic records have been studied by various investigators in the past. Such pulsations were believed to be caused by hydromagnetic waves generated in the upper atmosphere (Lehnert, 1956). The possibility of pulsations caused by hydromagnetic waves in the exosphere was discussed by Kato and Watanabe (1955, 1956) and Kato and Akasofu (1956). Obayashi and Jacobs (1958) from their calculations of the hydromagnetic wave propagation velocity along the geomagnetic lines of force, concluded that these waves are responsible for the long-period pulsations in high latitudes. Matsuura (1961) concluded after comparing the long period pulsations at high latitudes, with those occurring at the same time in mid and low latitudes, that the auroral zone pulsations are caused by the propagation of Alfven waves along geomagnetic lines of force from outside the Earth, whereas the ones near the equator are caused by the magnetic-acoustic waves. Mitra (1952) assumed that pulsations were caused by currents flowing the local regions of the upper atmosphere over the place where they are observed, as they indicate a local characteristic. Sato (1962) considered these pulsations to be due to localised small-scale ionospheric currents generated by the precipitation of charged particles from the outer magnetosphere. He observed that these pulsations occur frequently on days with high Σ **Kp** as compared to days of low Σ **Kp**; however they did not necessarily occur during time-intervals of severe magnetic activity. The local time of occurrence can vary from place to place, and it does not depend on the level of magnetic activity (Sato, 1965).

The closely-spaced magnetometer arrays in the northern auroral region were used by different investigators to understand the auroral current systems. Andre and Baumjohann (1982) Studied the pulsations to understand the eastward-drifting omega bands. Aikio and Kaila (1996) studied the movement of westward travelling surges and Bosinger *et al.* (1996) for the study of pulsating arcs. It is not feasible to operate a large number of magnetometers in an array in Antarctica, because of the harsh terrain and climate. The few works include Dunlop *et al. (*1994), who used the widely-spaced Australian Antarctic Stations for the study of the characteristics of long period geomagnetic pulsations. Such widely-spaced networks cannot be used to study the movement of small-scale auroral current systems generated by charged particle precipitation, as the scale-sizes of these currents are of the order of 100-200 km.

Experimental Set-up

A fluxgate magnetometer set-up (block diagram shown in **Fig.2)** is operated at MAI round-the-year recording daily variation (DV) and magnetic pulsation (MP). The pulsations are recorded using electronic filters to retain frequencies between 33 MHz and 0.33 MHz. The data is recorded in analog mode on strip-chart recorders and in digital mode on solid state data loggers at 1 min and 2 sec sampling intervals, respectively. The DV data on analog chart recorders is recorded at chart-speeds of 3 cm/hr, and sensitivity of 100 nT/inch while MP data is recorded at chart speeds of 12 cm/hr and sensitivity of 20 nT/inch. It is the analog data which is used for this study and we are in the process of plotting the digital data for further study.'

The magnetometers were simultaneously operated at the three stations during 16-31 Jan 1996. After careful scrutiny of the daily variation data, selected pulsation segments were chosen during magnetically quiet times and disturbed times. Similar pulsations recorded at the three stations during Quiet (Q), Moderately Disturbed (MD) and Disturbed (D) periods were selected and. analysed. The degree of disturbance was decided from the 3- hourly Kp indices, which broadly speaking, is a measure of the level of magnetic activity for mid-latitudes.

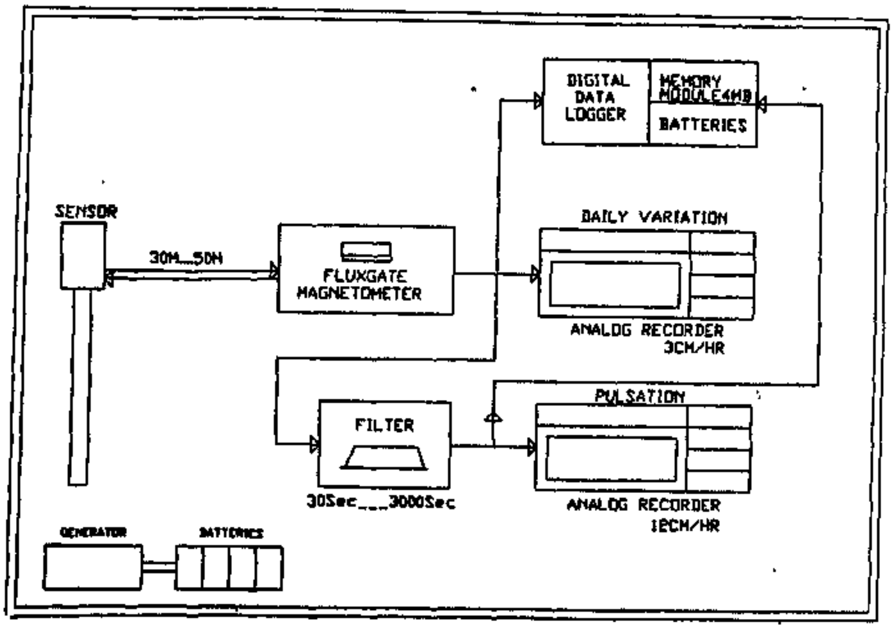


Fig.2: Block diagram of the fluxgate magnetometer set-up used at the three locations. The data is acquired in both analog and digital form

Observations and Discussions

Quiet day pulsations:

Quiet day pulsations on 21 Jan 1996 : Fig.3a shows the events recorded at MAI and OR on 21 Jan, 1996. Unfortunately, the recording at DG station was not possible because of lack of power due to rapid battery drain. This event

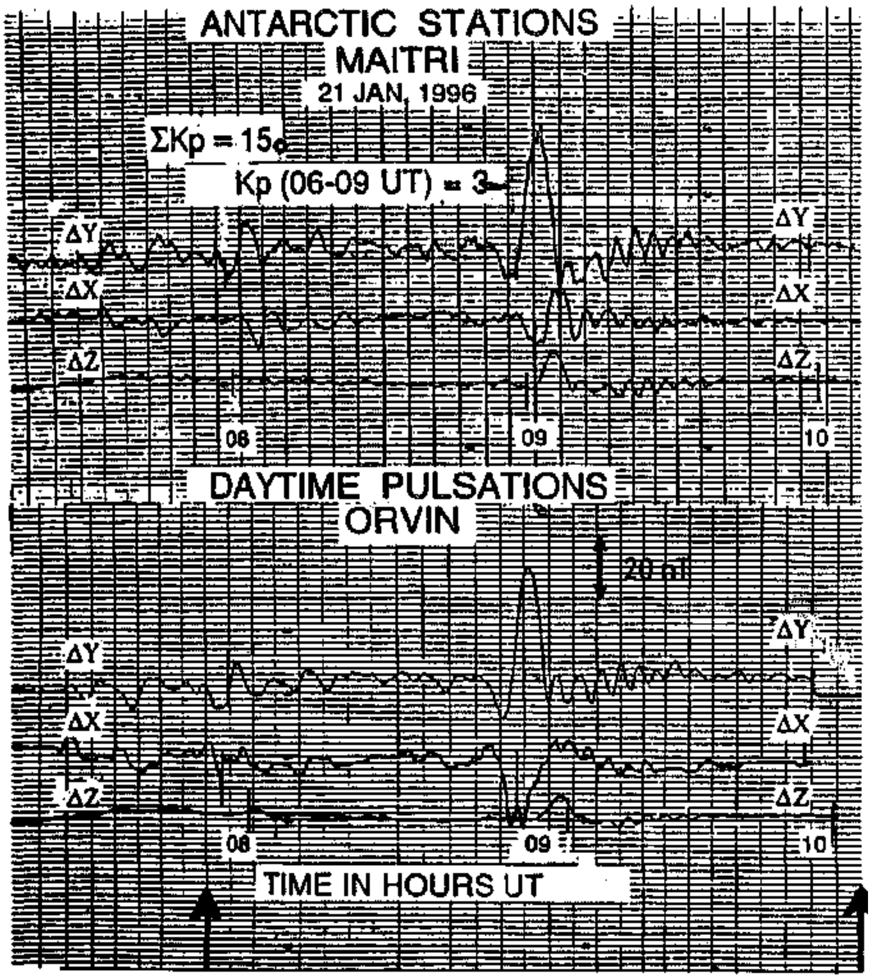
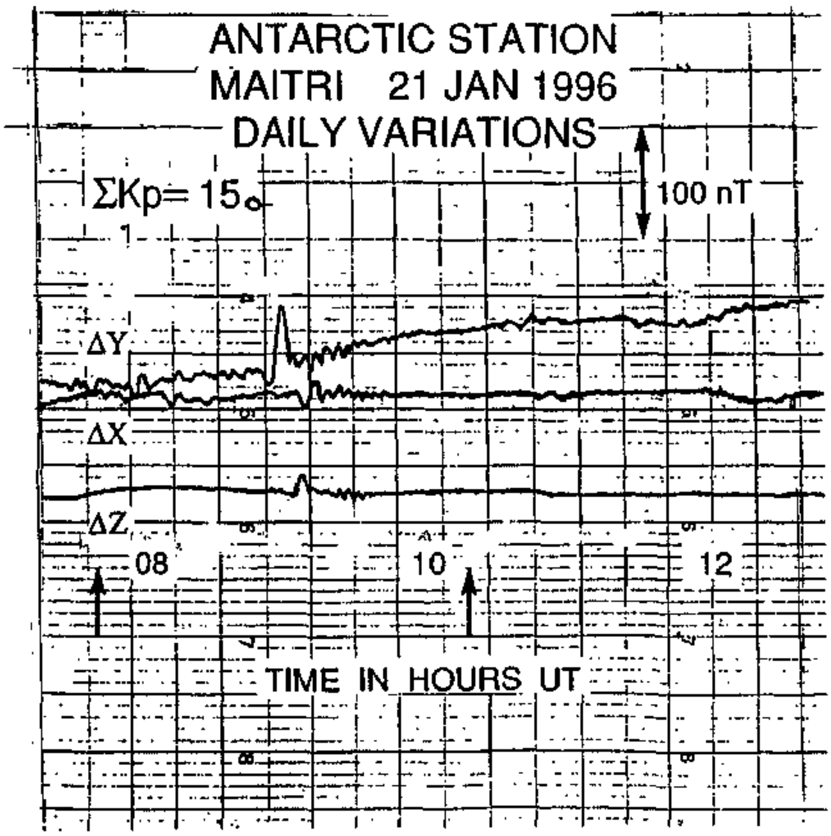


Fig.3a: Simultaneous geomagnetic pulsations experienced at the two locations MAI and OR on 21 Jan 1996 between 0800 and 1000 UT. The drift speeds of the small-scale ionospheric current systems are estimated from the time lags in similar pulsations

recorded on a moderately quite day during morning hours, shows a train of magnetic pulsations (between 08-10 UT) recorded at both the stations. The Σ Kp for this day is 15_o and the interval (06-09 UT) during which the pulsations are studied (strictly speaking 08-10 UT) has Kp=3-. The Kp values for the interval 03-06 UT and 09-12 UT (not shown here) are 1 + and 2_o, respectively. Large pulsation activity is observed in Y and X components but the Z trace is almost flat till 09 UT with mild pulsation activity after that. One major difference between the AX variation at the two station is reverse signature in X component at 09 UT. This can be due to latitudinal variation in current direction, and the two stations recording the effect of opposite/limbs of the current loop. The high Kp value of 3 for this interval, and the variations and pulsations recorded in X and Y components, possibly suggest the distant effects of the fact



Fig,3 b: The pulsation segments are chosen by scanning the daily variation data. Mild pulsation activity is observed during 08-10 UT in the data the DV data for this day shows a prominent event recorded around 09 UT in the Y component **(Fig.3b).** Eight clear sets of pulsation (within the interval demarcated by arrows) were chosen. The average drift speed estimated for these events worked out to be 0.925 km/sec. The time-lag in these pulsations show that the current system to be moving'from west of east.

Pulsations on moderately quiet day 22 Jan 1996 : Fig.4a shows events recorded on 22 Jan 1996, again at MAI and OR stations only (no recording was possible at DG station for the a 'entioned). While **Fig.3a** represented the events in the morning sector, **Fig.4a** represents events recorded in the dusk sector. This was another moderately quiet day with $\Delta Kp = 13o$ and

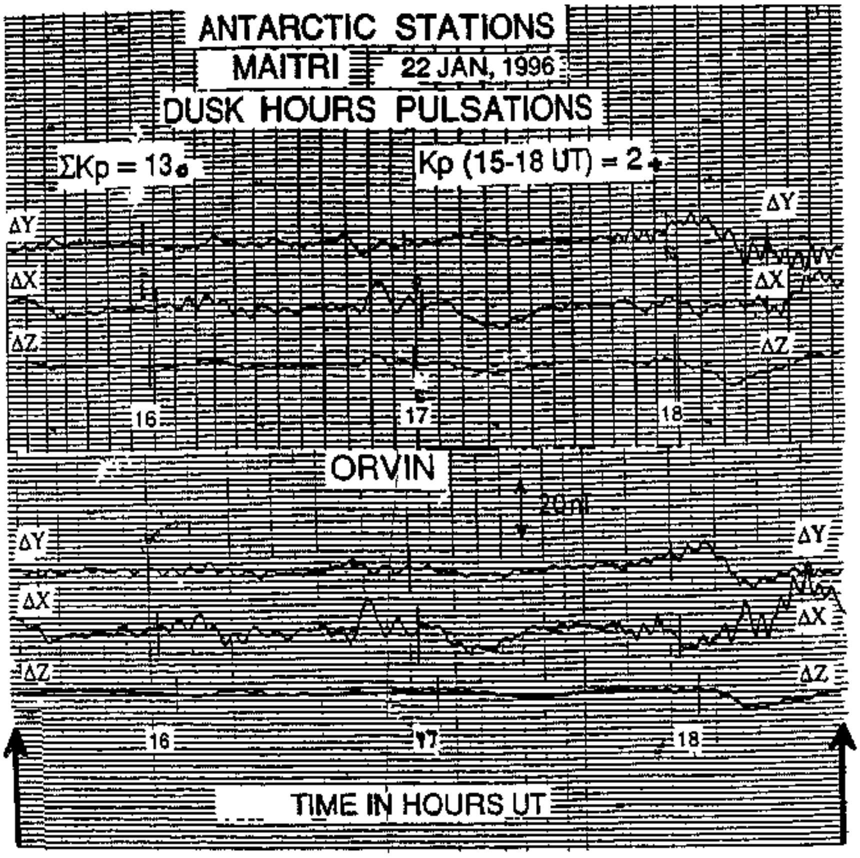


Fig.4 a: Dusk hour pulsations recorded at MAI and OR on 22 Jan 1996 between 1600 and 1800 UT. Notice that the magnetograms indicate quiet conditions and the pulsations are of very small amplitude.

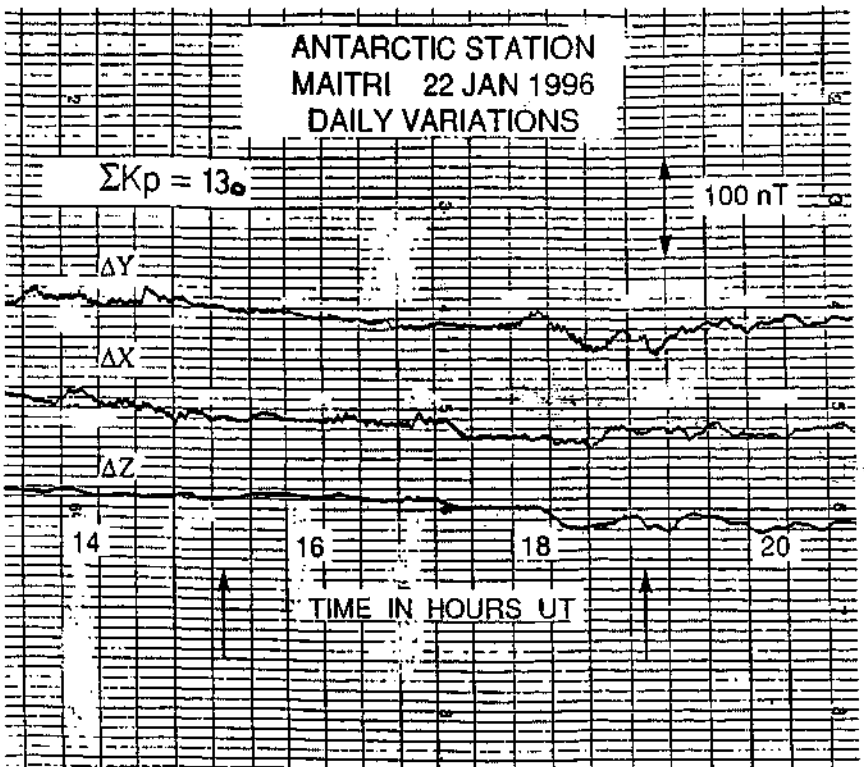


Fig.4 b; Daily variation data for the same segment on 22 Jan 1996

the Kp for the intervals 12 - 15 UT, 15 - 18 UT and 1 8 -21 UT being 2_0, 2 + and 2_0 respectively. The daily variation data for this day **(Fig.4b)** shows very mild pulsation activity between 1600-1900 UT. The pulsation activity is observed in X and Y components, whereas the Z component shows very little variation as in Fig.3a. The average drift speed for this day from a set of four pulsations events (in the interval marked by arrows) was estimated **to** be 1.37 km/sec.

Pulsations during disturbed conditions *:*

Pulsations for moderately disturbed period 25-26 Jan 1996 : Fig.5a shows long period pulsations recorded during moderately disturbed conditions. The events recorded on 25-26 Jan shown here follow substorm activity after 01 UT on 26 Jan **(Fig.5a).** While 25 Jan was a quiet day with ΣKp of 11 +, 26 Jan was moderately disturbed with Σ Kp=l 6_. The Kp for the events chosen during the interval 21-00 UT on 25 Jan is 2+. **Fig.5b** shows that the substorm recorded between 01-03 UT on 26 Jan is preceded by considerable pulsation activity. Six

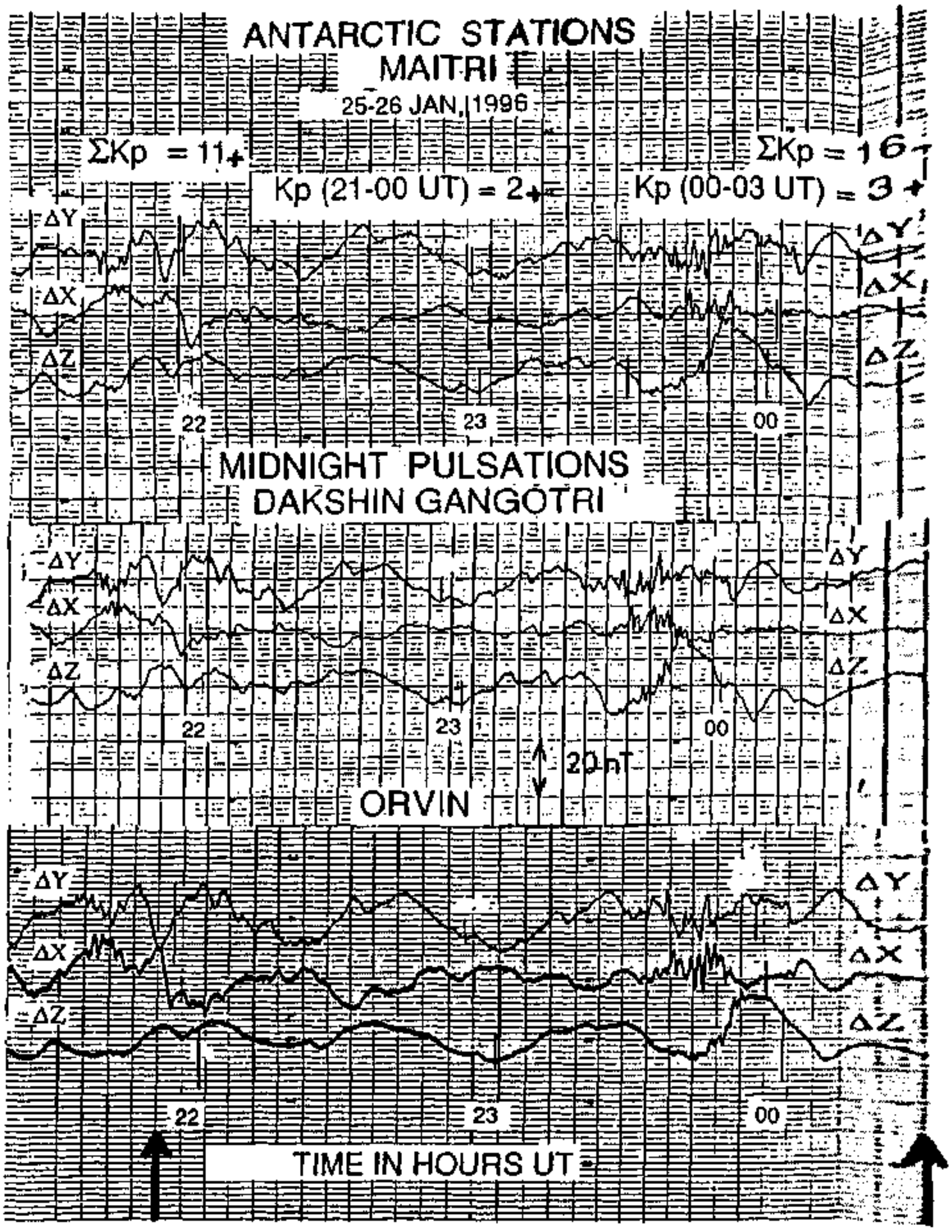


Fig.*5a: Midnight pulsations recorded on 25-26 Jan 1996 at the three locations between 2200 and 0000 UT.*

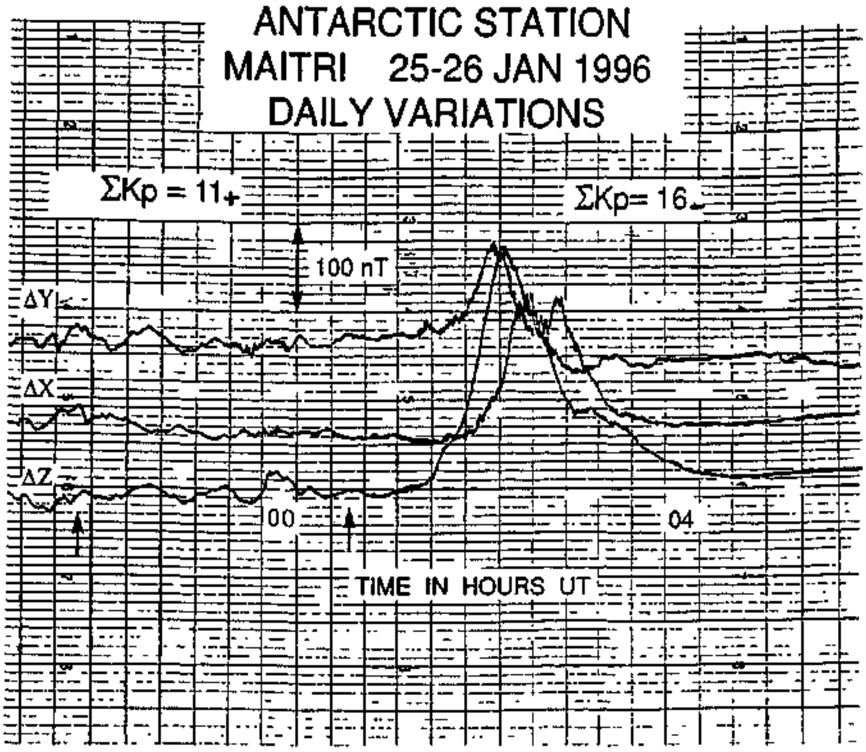


Fig.5b:Notice that these pulsations preceded the substorm after 0/30 UTseen in the daily variation data from the MAI station

sets of pulsation events (within the interval marked by arrows) were chosen, and the drift speed on this day was estimated to be 0.83 km/sec.

Pulsations for disturbed period of 28-29 Jan 1996: **Fig.6a** shows the events recorded on 28-29 Jan 1996. The DV for this day **(Fig.6b)** shows the pulsations occurred during moderately disturbed/disturbed conditions. While 28 Jan was a moderately disturbed day (Σ Kp = 15o), 29 Jan was a disturbed day with storm and substorm activity (Σ Kp=27o). For this interval we observe that the amplitude of the pulsations at OR in X and Y components is much larger than those observed at MAI and DG; this can be due to field-aligned currents feeding directly into the ionosphere over OR. The amplitude in the Z component is however small at OR compared to MAI and DG. The pulsations selected for study lies within the interval marked by arrows in **Fig.6a.** Large drift speeds were obtained on this day, varying between 3 and 18 km/sec. These high velocities can be due to the westward travelling surges (WTS), which carry very strong currents, and could cause large drift speeds.

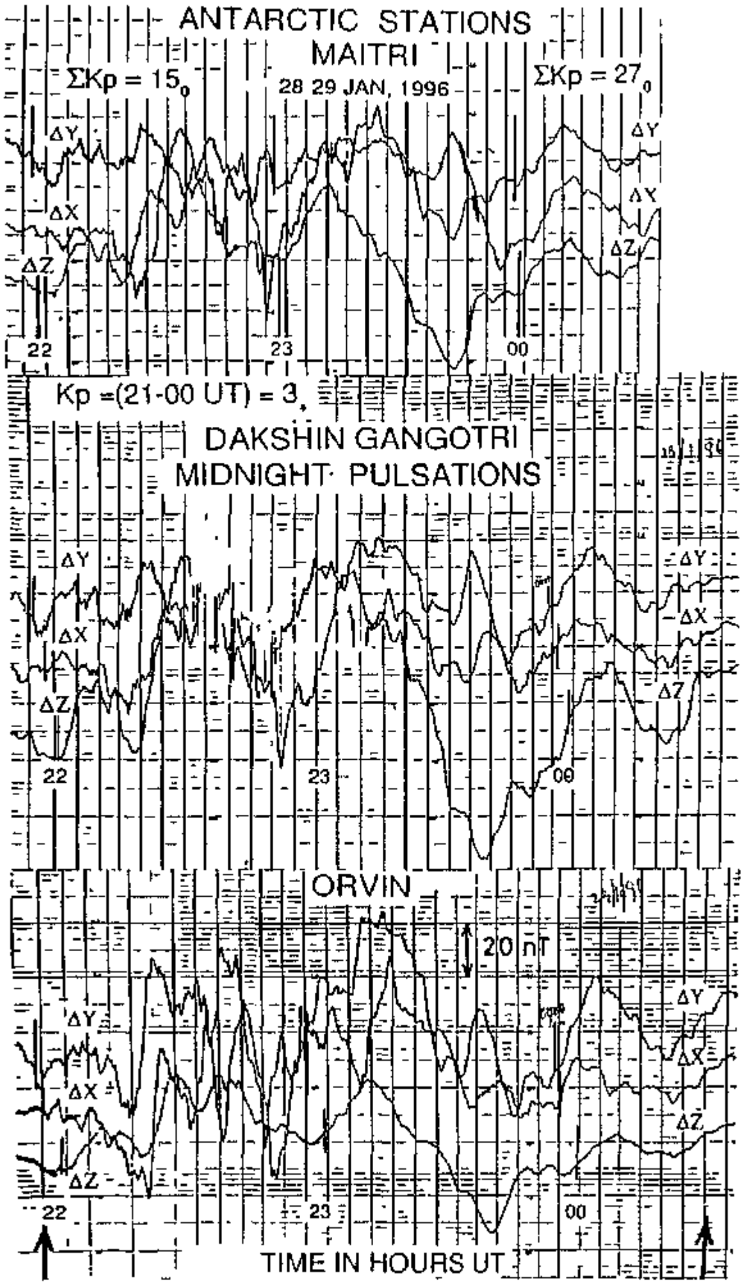


Fig.6a. Long period pulsation activity with shorter period overriding them recorded at the three locations MAI, DG and OR during 28-29 Jan 1996, between 2200-0000 UT

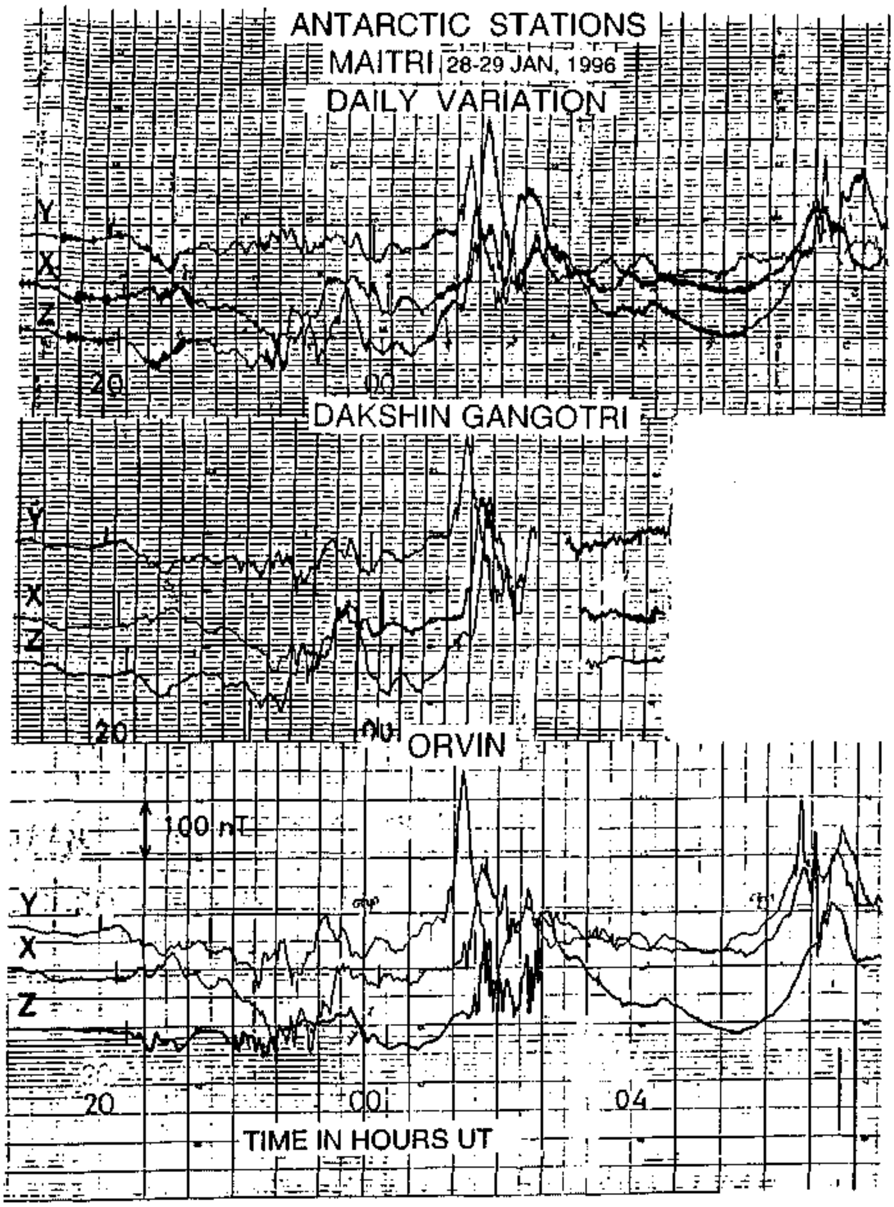


Fig.6b: The daily variation shows the prevalence of highly disturbed magnetic conditions from 1800 to 0800 UT, the period of pulsations studied

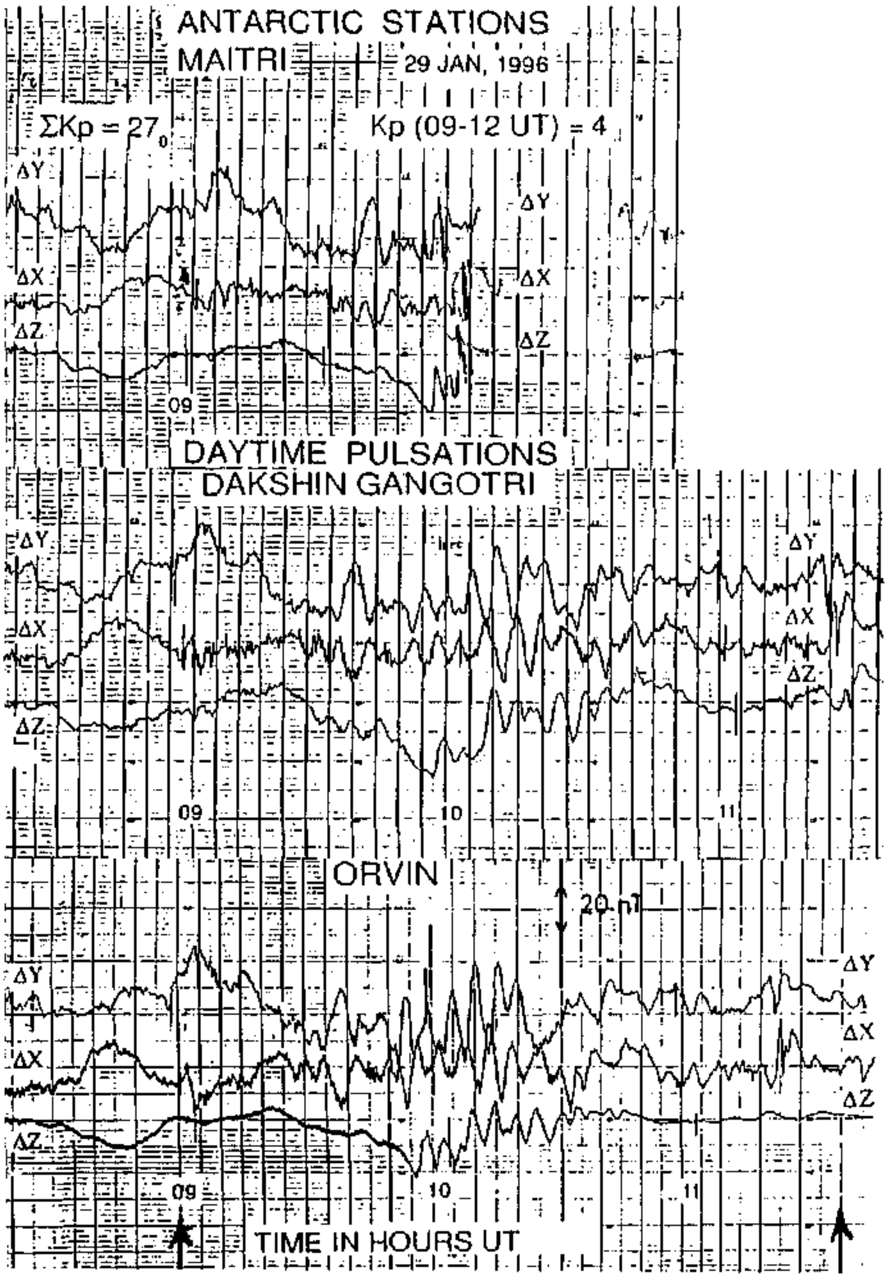


Fig.7a: Daytime pulsation activity recorded at the three locations on 29 Jan 1996 between 0900 and 1130 UT

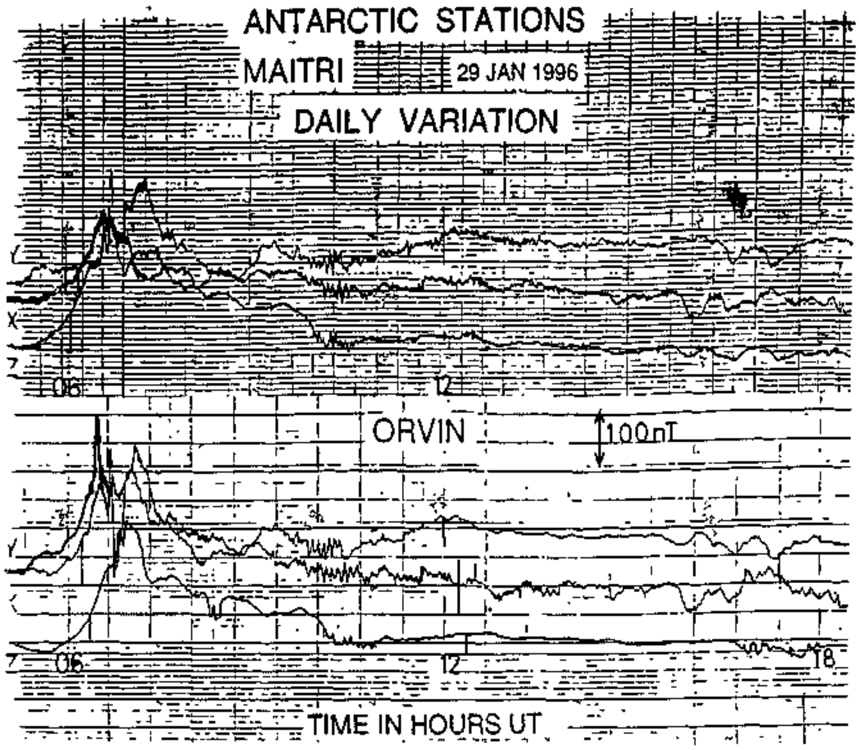


Fig. 7b: The daily variation, data from the two stations MAI and OR for the same day shows the stormy conditions prevailing on this day

Pulsations following an auroral substorm : **Fig.** 7a and 7b shows a train of pulsations recorded on 29 Jan. The amplitude differences between the stations show characteristics similar to that noticed for the event. While **Fig.6a** refers to the pulsation activity during night hours, **Fig.7a** represents the events during daytime. The pulsation recording at MAI was disrupted on this date due to recorder problems, and no recording was possible for about 4 hours after 10 UT. Six clear sets of pulsations were chosen for this day (within the time-interval marked by arrows) in Fig.7a. The drift speed for this day varied between 0.94 km/sec and 3.44 km/sec.

Conclusions

Knowing the exact distances between the two stations taken by GPS (Global Positioning System) aboard helicopters, (the accuracy of which is within five feet), and the time-lags in similar pulsations between two stations, the average drift speed for the moderately quiet days 21 and 22 Jan 1996 **(Fig.3a, 3b,** and **Fig.4a, 4b)** work out to be 0.925 km/sec and 1.53 km/sec respectively. The velocity for the many pulsation events studied on these two days range from 0.68 km/sec and 1.85 km/sec, which is within reasonable limits of what other investigators have found.

We have analysed pulsation events other than the ones discussed above, and find that during quiet times the velocities are low and the time-lags quite large, in contrast, during disturbed conditions, the time-lags are much smaller. On 28-29 Jan, 1996 **(Fig.6a** and **6b)** which was a disturbed day with marked storm/substorm conditions, large values of the order of 18 km/sec, were obtained for some pulsations. These could be caused by westward travelling surges.

Models of Auroral Current Systems

Fig.8 and Fig.9 show the different types of current systems and the type of variation we expect due to these current systems. Fig.8a shows the eastward auroral electrojet current system which leaves a positive signature in the X component on a ground based magnetometer with a maximum variation seen directly under the current. The Z component shows a negative to positive latitudinal variation as one goes southwards for an eastward auroral electrojet. **Fig.8b** shows the magnetic signatures associated with the westward auroral electrojet which leaves a negative signature in the X component with the maximum variation directly under the current. The Z component shows a positive to negative latitudinal variation as one moves southwards. It is thus seen that the ground based magnetic signatures of the westward auroral electrojet are just opposite to that seen for the eastward auroral electrojet. Hence, through careful observation of the ground based signatures, one can summarise the type of current flowing overhead in the ionosphere. There are other complicated small-scale current systems which flow in the ionosphere during substorm conditions and which are superposed on ionosphere during substorm conditions and which are superposed on the large-scale eastward and westward auroral electrojet currents shown in **Fig,8.** Examples of these complex substorm current systems are shown in **Fig.9.** The arrows of the full curve indicate the paths of least resistance taken by the currents. The crosses and the dots indicate the presence of field-aligned currents (fac); currents which flow from magnetosphere to ionosphere are indicated by crosses, while as the currents flowing from ionosphere to magnetosphere are indicated by dots. The eastward drifting omega bands drift from the midnight towards the dawn sector (Fig.9a), while as the westward moving surges drift from the midnight to the dusk sector **(Fig.9b).** Each of these leaves characteristic pulsation signatures on the auroral magnetograms, and these signatures enable one to diagnose the presence of

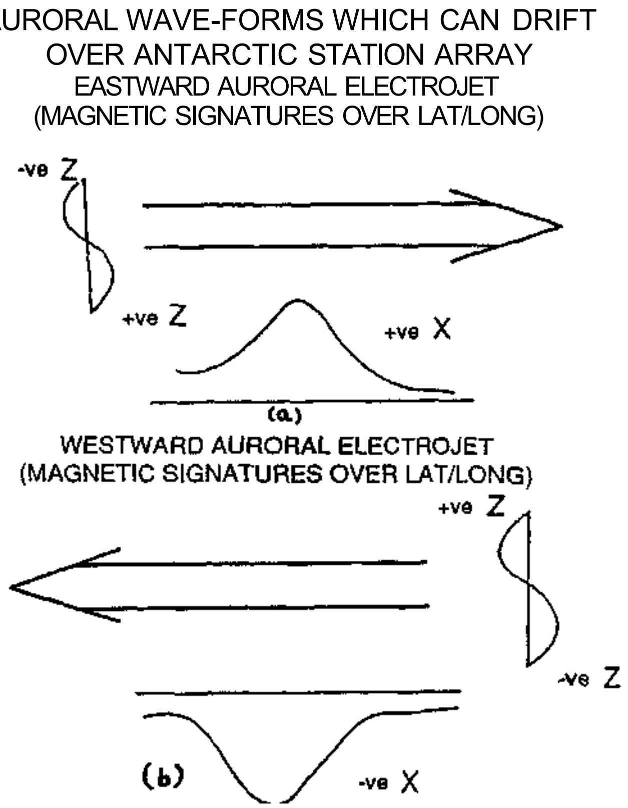


Fig.8 : A ground based magnetometer moving in latitude under the current would sea a +ve X component deflection which is maximum just beneath the current. Similarly, the magnetometer would register a vertical component which changes from a+ve to -ve deflection as one moves southwards (Fig.8a). Similarly, a westward auroral current would leave reverse signatures in the X and Z components as shown in Fig.8b.

these complex current systems overhead. It is beyond the scope of this work to discuss the detailed signatures, but a treatment of these is given by Kamide and Baumjohann 1933.

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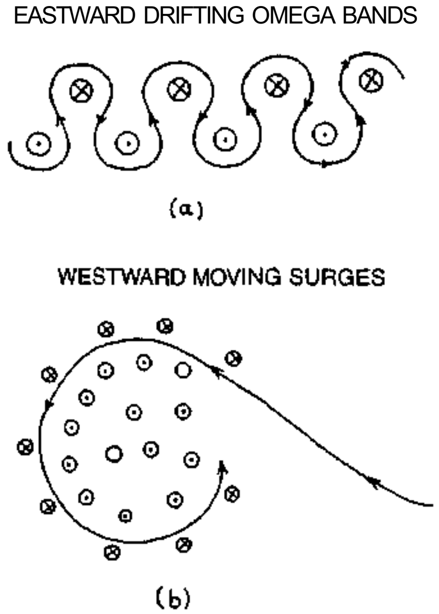

Fig 9 The midnight auroral sector is the region where substorm energy transferred from the magnetosphere to ionosphere deposits itself .The precipitating electrons and the fieldaligned currents (fac) which give rise to small-scale disturbed time auroral currents, manifests themselves as the omega bands (Fig 9a), which drift eastward towards the dawn sector. The westward travelling surges (WTS) drift from the might night to dusk sector (Fig 9b) It is these current systems which are mainly responsible for giving rise to rapid pulsation activity on auroral magnetograms during highly disturbed conditions

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