Eleventh Indian Expedition to Antarctica, Scientific Report, 1995
Department of Ocean Development, Technical Publication No: 9, pp. 87-101

Changes in the Auroral Electrojet Currents Inferred from Geomagnetic Field Variations at Maitri and Northern Conjugate Stations

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Abstract

Behaviour of geomagnetic variations over Maitri station, Antarctica through a calm to moderately calm and finally into a highly disturbed day, has been recorded. The data has been synthesized against similar observations made in two observatories nearest and equidistant from a point in northern hemisphere which is conjugate to Maitri in southern hemisphere.

Introduction

The Indian Antarctic stations Dakshin Gangotri (DG) and Maitri (MAI), during magnetically quiet times occupy a sub- auroral position i.e. they lie just equatorward of what is known as the "auroral zone". The auroral zone defines a narrow band of latitudes lying between about 60°-70° magnetic latitudes, where the optical atmospheric phenomenon of "aurora" occurs most frequently on a daily basis. Few space phenomena are linked as closely as aurora and variations in the geomagnetic field. It is the configuration of the geomagnetic field which decides the latitude at which auroral displays occur; and it is the energy state of the geomagnetic field which decides the form, fine structure and colours which auroral displays will take.

The aurora occurs over an oval shaped region circumscribing the high latitudes around the Earth's magnetic poles (Hargreaves,1992). During magnetically Quiet times, the auroral oval lies between 65° and 70° magnetic latitudes as shown in Fig 1(a). During times of magnetic Disturbance, the oval expands, or moves equatorwards to occupy the 60°-65° latitude position as shown in Fig 1(b). The Indian stations DG and MAI which occupy a peripheral position during Quiet times, move directly into the auroral oval during Disturbance as illustrated in Fig 1. This confers a definite advantage on the Indian

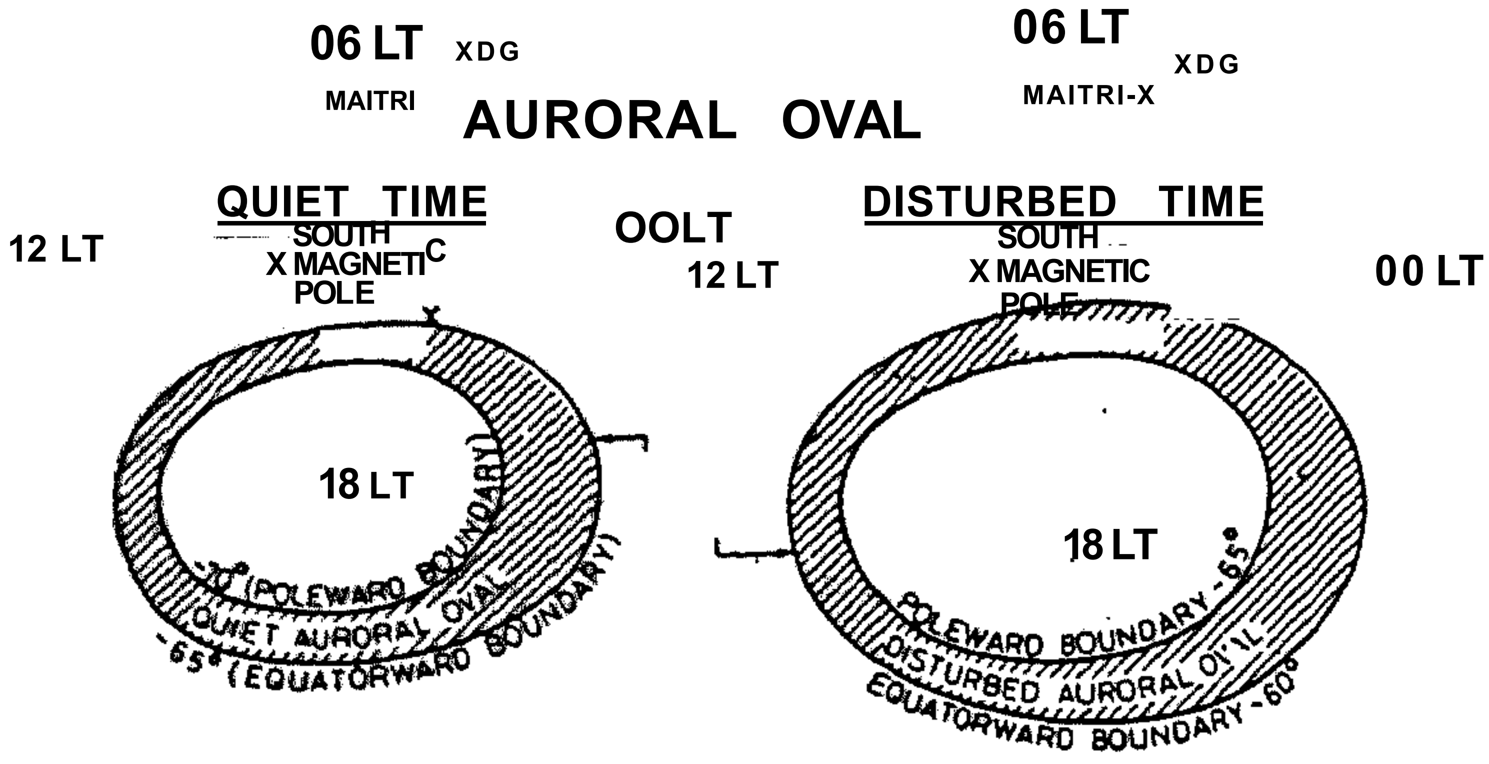

Fig 1: The Indian Antarctic stations Maitri and Dakshin Gangotri (DC) (a)lying just outside auroral oval during magnetically quiet times; (b) moving into the auroral oval during magnetic disturbance.

Antarctic stations as they provide a Quiet time non-auroral reference base against which the Disturbed time auroral behaviour can be judged.

The auroral regions of Earth play a special role in transfer of energy between the distant geomagnetosphere and the Earth's near space environment i.e. the ionosphere. Thus energy-coupling occurs through the precipitation of solar wind particles to form field-aligned currents (FAC) between the magnetosphere - ionosphere system. The FAC originate in the Central Plasma Sheet (CPS shown hatched in Fig 2) which is located 10 to 100 Earth radii (1 Earth radius = 6370 km) distance away. This region gets filled with solar wind particles which enter through the nightside magnetospheric tail. The Earth's magnetic field lines embedded in the CPS region preferentially channelise these solar wind particles towards the northern and southern auroral latitudes marked as black arcs In Fig 2. Intense electric currents at about 10 amps are generated at ionospheric heights of about 100 km over the auroral zone. These generally flow in an east-west direction and are called Auroral Electrojet (AE) currents. During magnetically Quiet times, the AE flow from the noonside to nightside in the auroral oval; thus they are directed westward in the dawn sector, and eastward in the dusk sector. During magnetically Disturbed times, quantised participation of solar wind particles from the CPS into the auroral ionosphere takes place more frequently. At such times e.g.during storms and sub-storms, FAC intensify greatly in the nightside auroral region, and small scale currents arc superposed on the normal background AE. These secondary disturbed-time currents are mobile and can move towards both dawn and dusk sectors .from the midnight sector. These various types of current systems leave their distinctive magnetic signatures in geospace. A ground based magnetometer located in

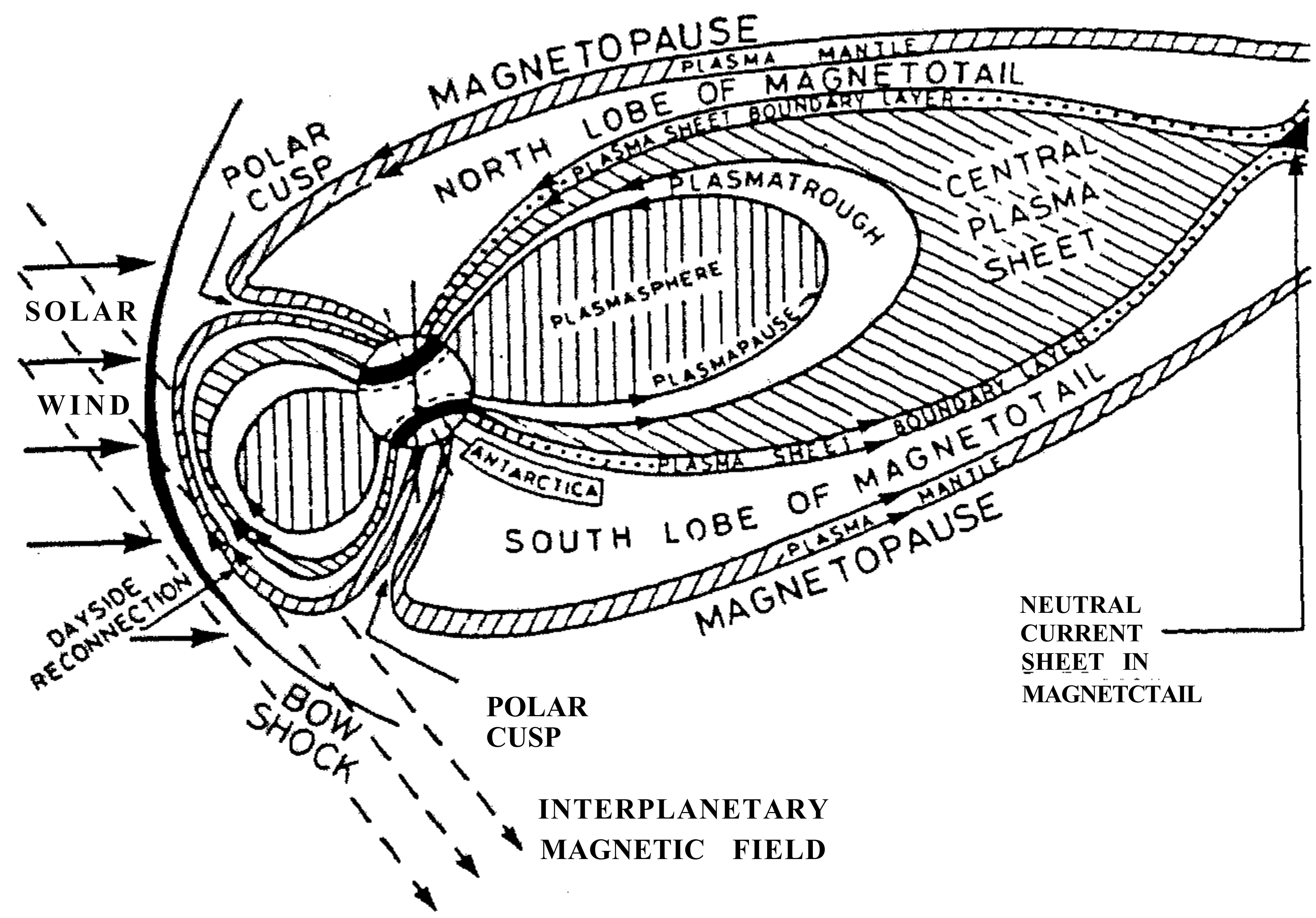

Fig 2 : Polar cross section of the Earth 's Mugnetosphere showing different regions of plasma.

the auroral region readily records these signatures in the form of long-period and short-period fluctuations in the magnetic field.

In this work, the long-period magnetic field variations and the short-period magnetic pulsations recorded at the Indian station Maitri during January 1992, are used to understand changes in the intensity and position of AE currents and the FAC associated with magnetic disturbance.

Experimental Set-Up

During the austral summer of eleventh Indian expedition to Antarctica (1991-92), Indian Institute of Geomagnetism simultaneously operated three fluxgate magnetometers at three locations viz.,Maitri(7G°46'S:l I°45'E),Dakshin Gangotri (70°G5'S: 12°E) and Payer mountains(71 °5 V S: 14°29'E). These stations were located at the vertices of a triangle with sides varying between 75 km and 200 km. Although scheduled to operate for a fortnight, these three stations could run together only for four days from 6 to 9 January 1992 due to highly inclement weather conditions at shelf and the mountains.

At Maitri however, because of full fledged facilities for Antarctic studies, recording of geomagnetic variations could be continued without, interruption.

and it is these data which are used in the present work. The geomagnetic field changes in the three orthogonal components X,Y and Z were recorded in analog as well as in digital mode. The Daily Variation (DV) records were obtained on normal run of 3 cm/hour. Micropulsatlon (MP) data was obtained on similar chart recorders at rapid run of 12 cm/hour after filtering out all pulsations with time period between 30 seconds and 3000 seconds. The sensitivity of chart recorders were varied from 10 Volts (1000 nT) Full Scale Deflection (FSD) to 40 Volts (4000 nT) FSD, depending on the disturbance experienced by the magnetometers. A block diagram of the experimental set-up is shown in Fig 3.

Observations

The term conjugacy refers to certain similarities seen in geophysical signatures monitored in two ground based feet of a geomagnetic field line; these locations naturally lie in the northern and southern hemispheres of earth (Wescott, 1966). With the objective of understanding changes in the AE activity in northern and southern hemispheres, a conjugate area study was carried out to examine changes at the foot of the magnetic flux tube passing through MAI. The corrected geomagnetic coordinates of MAI are 62.4°S and 52.0°E, and its magnetic conjugate in the northern hemisphere lies in the north Atlantic ocean. The nearest observatories to the northern conjugate point happen to be NARS-

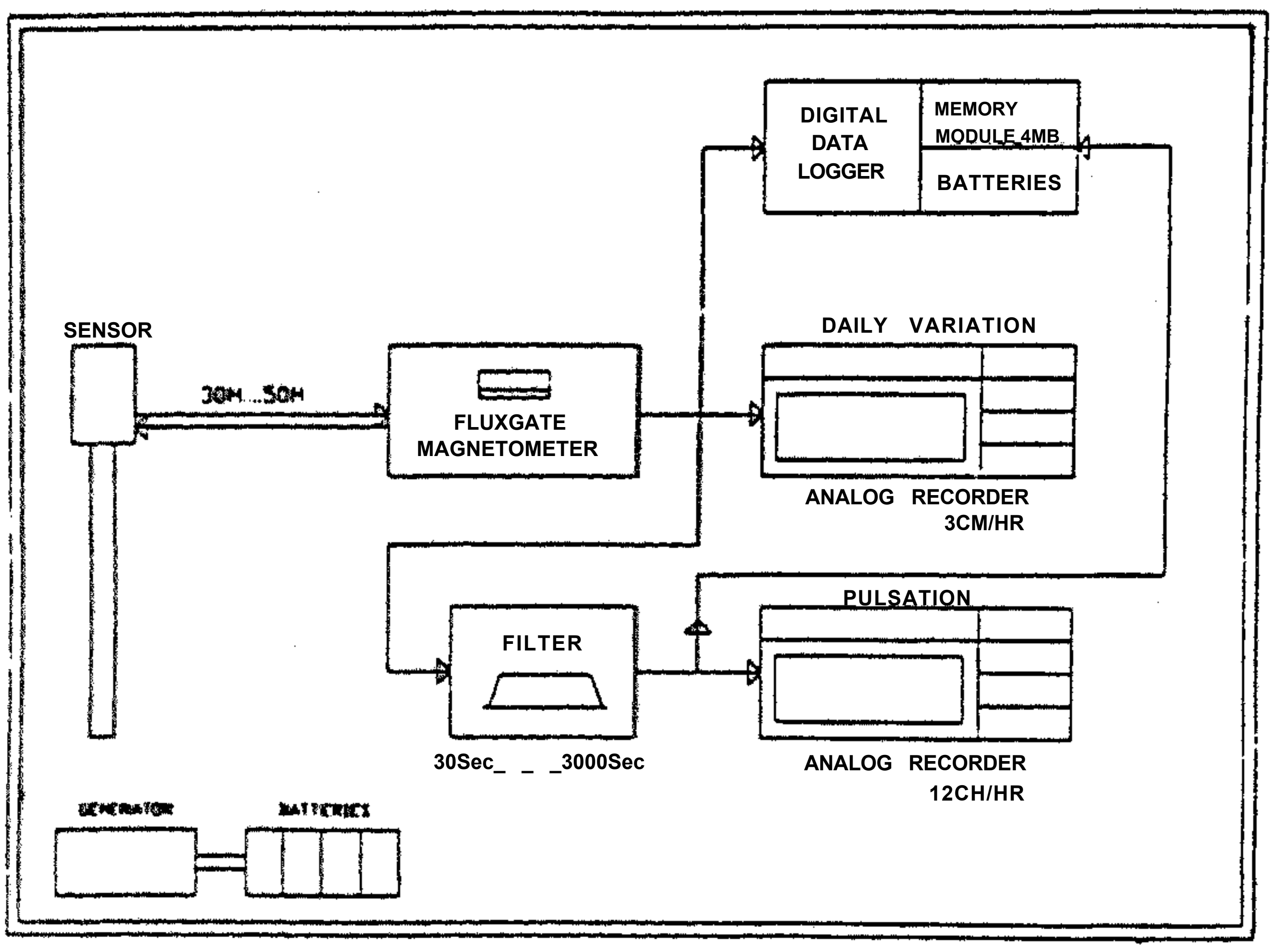

Fig 3 : Block diagram of Fluxgate Magnetometer set-up used to record daily variations amd pulsations in X, Y amd Z components of the geomagnetic field at Maitri.

SARSSUAQ (NAQ) In Greenland, and LEIRVOGUR (LRV) in Iceland; the two stations are roughly equidistant from the conjugate point. This aspect of magnetic conjugacy between MAI in Antarctica and, NAQ and LRV in the northern hemisphere is shown in Fig 4. The geographic coordinates, the geomagnetic coordinates and the L values of these conjugate area locations are shown in Table I. The L value refers to the distance away from centre of the Earth in units of Earth radii, of the equatorial portion of magnetic field line on which the station lies.

In the present work we study the north-south conjugate geomagnetic behaviour at these stations. The period covered is 6 to 9 January, 1992 which included a geomagnetic storm.

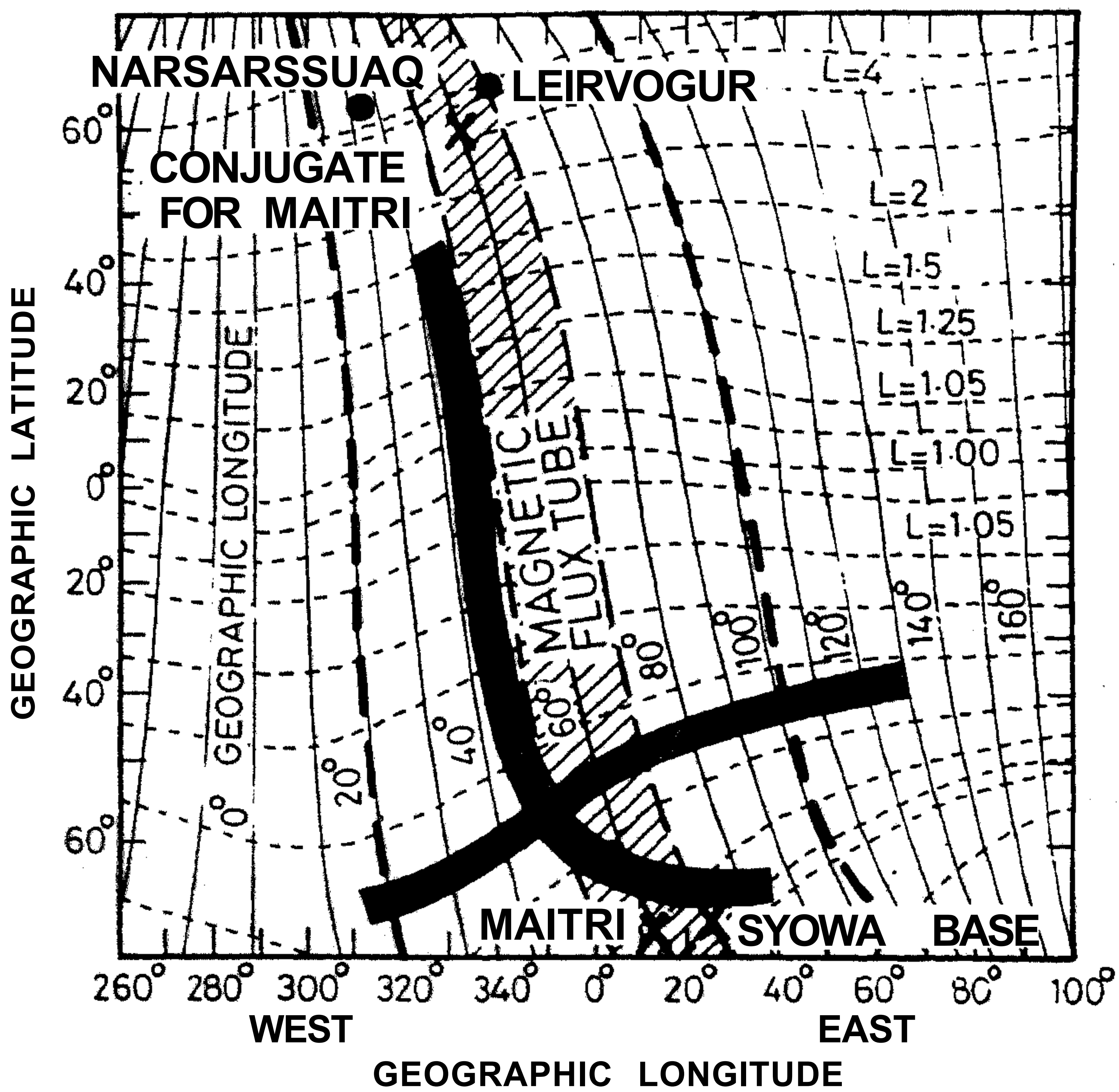

Fig 4 : Figure showing lines of geomagnetic longitudes and L-values for the locations studied. Maitri in southern hemisphere and its magnetic conjugate point in northern hemisphere denoted by crosses.

Table I

Station	Geographic		Corrected Geomagnetic		L Value	Dipole Coordinates	
	LatituPde	Long.	Latitude	Long.		Latitude	Long.
Maitri (MAI)	70° 46'S	11°45'E	62. 3°S	52.0'E	4.7	67°S	55°E
Narssarssuaq (NAQ)	61°10'N	45°2'W	68.73°N	44.17°E	6.4	70.78°N	38.7°E
Leirvogur (LRV)	64.18°N	21°7'W	66.82°N	69.53°E	5.7	69.90°N	72.2°E

Geomegnetic variations on 7 January-Pre-Storm day

In geomagnetic studies, the magnetometer records any of the three components of the geomagnetic field vector; these are variations in the north-south direction (can be recorded as the H component in magnetic north-south or as X component in geographic north-south direction), in east-west direction (can he recorded as D component which Is the angle by which magnetic meridian deviates from geographic north-south, or as the Y component along the geographic east-west direction), and as the Z component in vertical direction. Fig 5 shows the H,D and Z components recorded at the northern and southern stations on 7 January 1992, taken as a control day because it preceded a day of magnetic storm. Fig 5 and the figures which follow, have the format described in the following paragraph.

The topmost curve in each diagram shows one minute interval data of the relevant component for Antarctic station Maitri. Below this is given, in the form of a histogram, three hourly index of planetary magnetic activity Kp; this index indicates the degree of electromagnetic activity in the Earth's environment. Below the Kp index, are shown variations of the relevant, component for northern hemisphere stations LRV and NAQ. Further below are shown the X-ray count (wavelengths 1 - 8 Angstroms), and the electron count (energy exceeding 2 MeV),detected by the GOES-7 satellite on the same day. The GOES-7 satellite was positioned at 105°W. This data is obtained from bulletins of Solar and Geophysical Data published by National Oceanic and Atmospheric Administration (NOAA) of U.S.A.,located at Boulder,Colorado,U.S.A.

Fig 5 shows that the northern stations LRV and NAQ are typical auroral electrojet (AE) stations because they record an increase in the H component in afternoon sector, and a decrease in H component in the morning sector. This is consistent with the picture of an eastward flowing AE in the dusk sector and

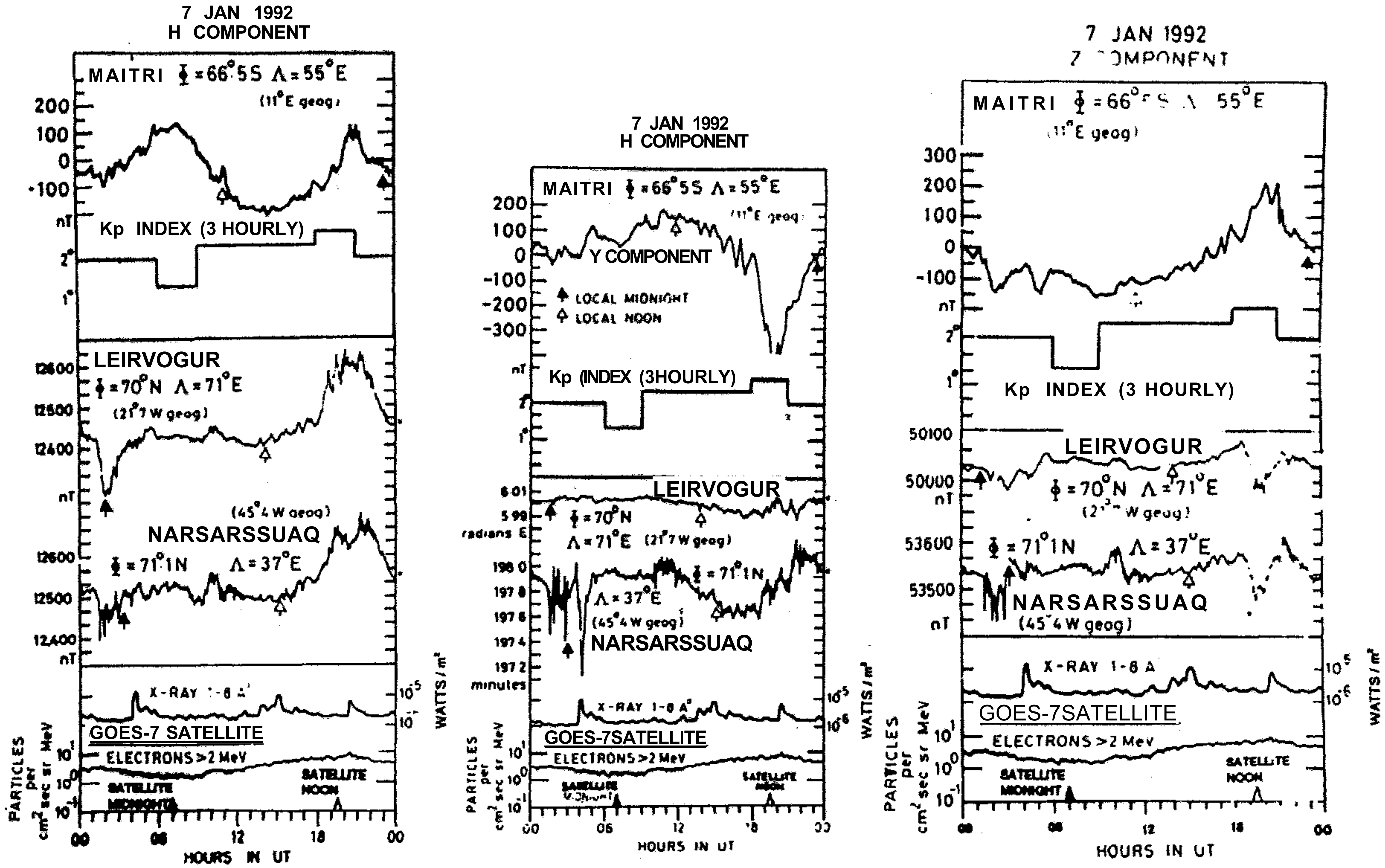

Fig 5 : Variations on pre-storm day (7 January 1992) of H,D and Z geomagnetic components at Maitri and northern conjugate stations. Lower parts of the blocks showing GOES-7 satellite measurements of X- rays of wavelength 1-8 Angstrom and electrons of energy 2 MeV.

westward flowing current In the dawn sector. MAI in the south shows similar characteristics in post-noon time sector, but the pre-noon signature varies from northern locations in that the negative is not as pronounced. This would suggest that MAI does not show a purely AE signature but one which is contaminated by other current systems associated with its sub-auroral location. One such current system is the Sq (solar quiet) current system which envelops the entire low and mid-latitude range.

Fig 5 shows that the D-variations at northern stations LRV an.d NAQ do not show a large change, thereby indicating the absence of any major FAC on 7 January 1992. The D-variation at MAI is also fairly flat over the major part of the day. A sharp drop is observed only after 18 UT. The Z-variations at LRV and NAQ also remain fairly flat over the whole day, but after 18 UT, a sharp drop is seen in the geomagnetic component, indicating presence of magnetic disturbance. At MAI the D behaviour in hours before 18 UT is similar to that at the northern stations, but after 18 UT, a positive variation is seen in contrast to the negative variations at LRV and NAQ. Sub-storm activity after 18 UT thus, leaves different signatures at the northern and southern locations in the Z component. The H and Z variations at LRV and NAQ in Fig 5, and the absence of any significant change in D at these stations, suggest that the disturbance at northern locations is mainly due to the east-west AE current, rather than to any fieid-aligned current. At MAI however, the disturbance after 18 UT with large changes in H, D and Z components indicate contributions from both east-west AE as well as from FAC.

Comparison of the GOES-7 satellite observations with the magnetic variations in Fig 5 shows that a sharp increase in X- rays occurs at about 20 UT, shortly after the auroral disturbance discussed above. A sharp change in X-rays is also seen shortly before 05 UT and this follows auroral activity seen in the H,D and Z components at LRV and NAQ. The X-rays detected by the satellite could be given off by energetic electrons precipitating into the auroral ionosphere along the geomagnetic field lines at these local times.

Geomagnetic variations on the storm day-8 January 1992

The three hourly Kp index figure shown in Fig 6 clearly indicates a marked rise in magnetic activity on this day following a storm sudden commencement (SSC). This storm, as seen on the magnetograms from MAI, started at 0245 UT and had an amplitude of 190 nT in the X component. The change in nature of the magnetic records between 7 January and 8 January 1992 is dramatic, at both northern and southern locations. Not only are the amplitudes of X and Y components much larger on 8 January, also there is occurrence of an increased high frequency component riding on the background curves on storm day. The amplitude of H (change in the H component) at NAQ in the pre-noon hours is about 425 nT on 8 January as compared to 75 nT the previous day. In the afternoon hours, NAQ sees a variation of 255 nT on storm day compared to 300 nT on 7 January. Corresponding changes in the H component at LRV and MAI are shown in Table II.

This large increase in the H component in the pre-noon and afternoon time sectors on the storm day shows up at MAI too. As can be seen from Table II, the variation in this component in pre-noon hours is 550 nT on 8 January compared to 250 nT on 7 January 1992. In the post-noon hours, it is 685 nT and 350 nT on 8 and 7 January, respectively. This implies that the influence of east-west current system over MAI had increased on 8 January. Table II also shows that in pre-noon hours, the variation in Y (east-west) component is 575 nT on 8 January against 200 nT on the previous day. In the afternoon hours these values are 910 nT and 600 nT for 8 and 7 January 1992. This shows that MAI was under influence of strong FAC on the storm day.

Long period variations in the D component at LRV and NAQ are also more enhanced on the storm day, but it is mainly the superposition of high frequency variations on D component which is manifest at these northern stations. The Z component on 8 January, in both hemispheres, shows far more disturbance, both in short period fluctuations and in long term variations, as compared to same on 7 January 1992. The range in variation in the Z component is shown in Table II. LRV and NAQ clearly show intense auroral activity but the variations in D component are less pronounced than at MAI. The large vari-

Table II

Date	MAI			LRV			NAQ		
	ΔX nT	ΔY nT	ΔZ nT	ΔHnT	ΔD rad/east	ΔZ nT	ΔH nT	ΔD min	ΔZnT
Prenoon 6 Jan. 1992	120	400	250	200	50	65	270	280	155
Afternoon	450	475	450	435	100	250	245	195	275
Prenoon 7 Jan. 1992	250	200	150	120	35	75	75	315	160
Afternoon	350	600	325	370	90	120	300	280	165
Prenoon 8 Jan. 1992	550	575	600	275	80	185	425	550	330
Afternoon	685	910	450	355	125	300	255	335	230
Prenoon 9 Jan. 1992	175	105	150	75	55	45	100	105	80
Afternoon	100	125	40	235	105	125	220	630	360

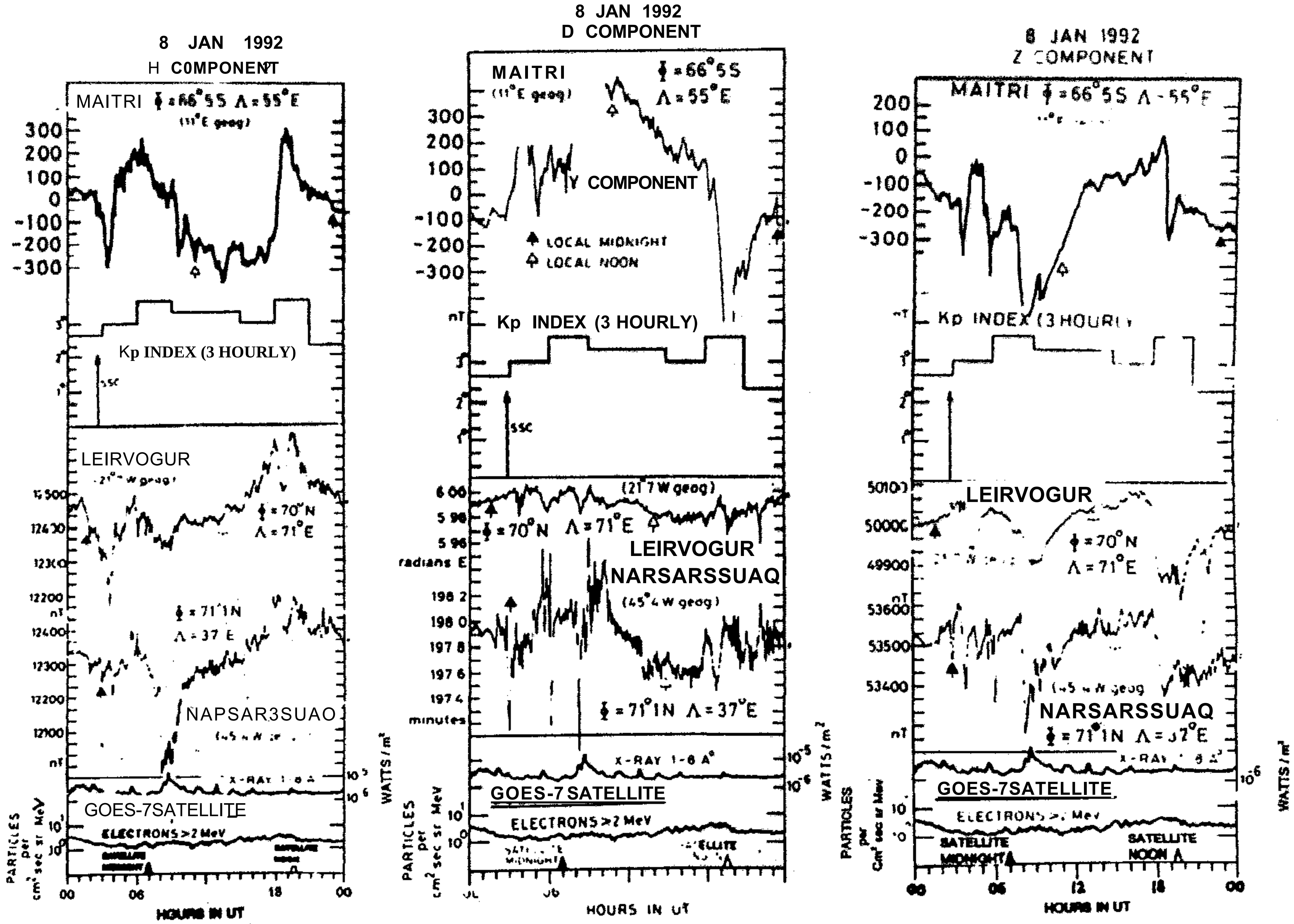

Fig 6 : Storm day (8 January 1992) variations of H,D and Z geomagnetic components at Maitri and its northern conjugate stations. The arrow at 0245 UT shows onset of magnetic storm.

ations in H, D and Z at MAI on the other hand, indicate that it took place under the influence of east-west auroral currents as well as FAC.

In-Fig 6, the most marked correlation between X-rays observed by the GOES-7 satellite and auroral activity is seen between 07-09 UT. The short period fluctuations in X-rays on 8 January are a little more prominent than on 7 January. Many of the X-ray fluctuations accompany the high frequency component in the magnetic variation at LRV and NAQ. The high energy electrons (2 MeV) recorded by the geostationary GOES satellite also tend to show more short-period fluctuations on 8 January than on 7 January. Clearly, the storm of 8 January has affected the electromagnetic field and energetic particle distributions at distances as large as 6.6 Re away from Earth.

Geomagnetic variations on 9 January 1992-very calm day

This post-storm day is in total contrast to what was seen on the day of storm (8 Jan 1992). Fig 7 shows that the Kp index remains below 2 for a substantial period of time between 06 and 21 UT. In fact, for most of this interval the Kp value is only 1, showing conditions of total magnetic calm. This is clearly reflected too, in the records at LRV and NAQ. After 06 UT the variations of H,D and Z are practically flat, showing none of the sharp sub-storm changes which are seen at the same places prior to 06 UT. A striking feature is the absence of pronounced pre- noon depression and afternoon increase in H (Figs 5 and 6). This would suggest that LRV and NAQ are no longer under the influence of auroral electrojet.MAI too shows H,D and Z traces,flatness of which are similar to the recordings at LRV and NAQ. The inference is that LRV and NAQ like MAI seem to have become sub-auroral because the AE currents moved polewards to higher latitudes. This is known to happen during very calm conditions. At such times there can even be 'theta aurora' with a polar auroral arc stretching across from noon to the nightside (Akasofu and Kamide,1987). The D variation at MAI is hardly 200 nT suggesting total absence of any FAC over the station. The Z variation at MAI is extremely small on 9 January 1992 when compared with the same on 8 January. All these features point towards total absence of AE activity over MAI.

The poleward movement of AE can be visualised from Fig 1. On 9 January 1992, the likely scenario is that the auroral oval would have shrunk further. It might have moved up to higher latitudes such that the equatorial border of the oval was at 70° geomagnetic latitude and the poleward border at 75°.

Geomagnetic variations on the moderately calm day-6 January 1992

In the earlier sections we discussed how the intensity and position of AE changed through a control day, a storm day and a very calm day. Now an example of H,D and Z variations on a typical day of moderate disturbance with a dKp of 22° is discussed. This is shown in Fig 8. The Kp index has remained

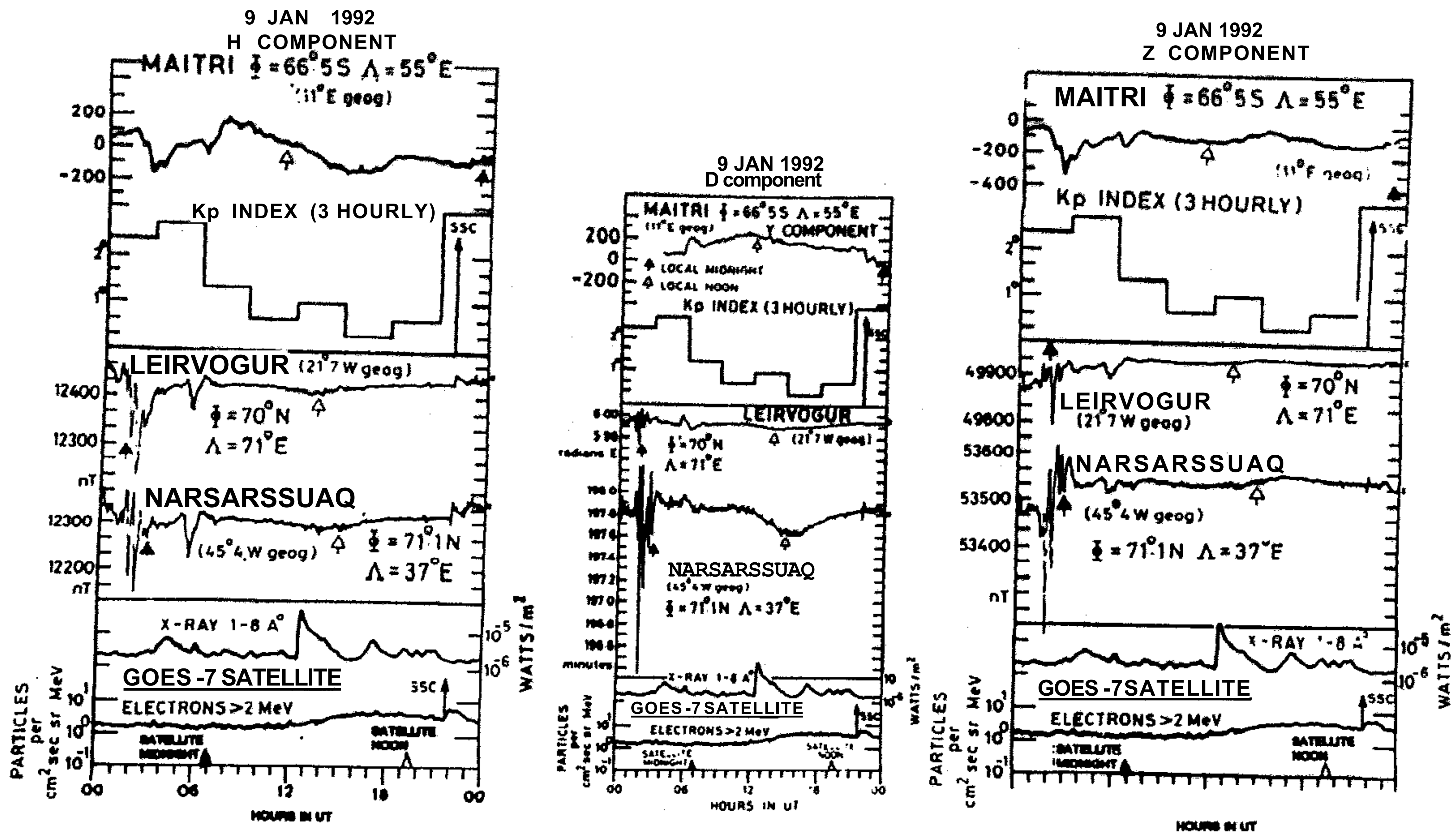

Fig 7: Post-storm day (9 January 1992) variations of H,Dand Z geomagnetic components at Maitri and its northern conjugate stations.

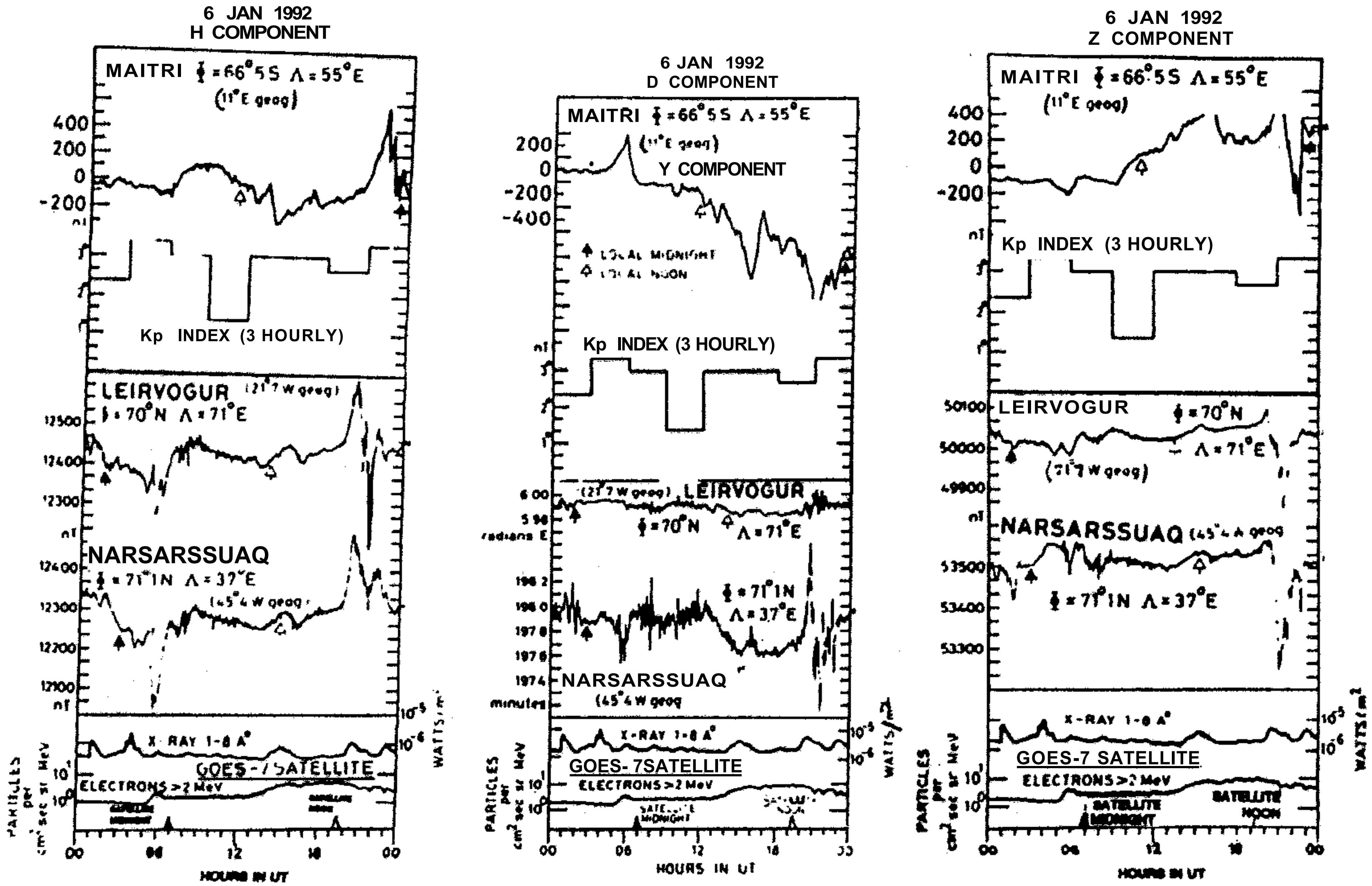

Fig 8 : Variation of H,D and Z components at Maitri and its northern hemisphere conjugate points on 6 January 1992, a moderately disturbed day.

at a level of about 3 for most of the day except over two short intervals, one soon after 00 UT and the other soon after 09 UT. On this day the decrease in H variation in the pre-noon hours characteristic of the westward AE and the rise in H variation in post-noon hours, characteristic of eastward AE are seen at LRV and NAQ. The same pattern is seen in the H component at MAI, showing the influence of AE currents; main difference being a pronounced decrease in the post-noon hours.

At all the three stations, short period fluctuations are superposed on the general diurnal trend. Sub-storm activity is seen simultaneously at all these locations in all three geomagnetic components after 19 UT, and a rise in X rays measured by the satellite is also observed. The GOES-7 satellite X-ray count shows a rise soon after 14 UT, and a similar rise is seen in the H and Z components at LRV and NAQ at the same time. There are two sharp peaks in X-ray flux between 00 and 05 UT. These could be connected with sub-storm type activity seen at LRV and NAQ. The 2 MeV electron flux shows a definite rise in level after satellite midnight but it is not visibly correlated with any special change in the magnetograms at either the northern or the southern stations.

Conclusions

During moderately quiet conditions (7 January 1992), while LRV and NAQ are located directly below the AE current system, MAI at the other end of the flux tube lies in the sub-auroral zone, just equatorward of the AE current system.

With increase in geomagnetic disturbance, the AE current system intensifies and moves equatorwards. LRV and NAQ continue to experience its geomagnetic effect. MAI now comes under the influence of AE in the southern hemisphere as seen from increased intensity of variations, in the H and Z components. The influence of FAC over MAI is clear from the large D variations.

With decrease in geomagnetic disturbance, the AE current system moves greatly polewards, and the LRV-NAQ pair which are normally electrojet stations, are no longer under the influence of AE currents. The Indian station MAI is even further from the influence of AE currents in the southern hemisphere.

A good degree of conjugacy is seen in the geomagnetic records between the northern and southern locations i.e. Leirvogur and Larssarssuaq in the north and Maitri in the south. This suggests that the currents causing the geomagnetic

variations at the ends of the relevant magnetic flux tube have a common origin in the deep, distant magnetosphere.

Acknowledgements

The authors are grateful to Dr.Thorsteinn Saemundsun of the Science Institute, University of Iceland, Reykjavik for kindly providing January 1992 magnetic data for Leirvogur; and to Dr.Eigil Friis-Christensen of the Danmarks Meteorologiske Institute, Kopenhagen, Denmark for providing data for Nars-sarassuaq. The authors express their gratitude to the Department of Ocean Development for supporting the studies at Antarctica and to the members of eleventh expedition team for their help during field work.

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