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RESPONSE OF THE 30MHz AND THE FLUXGATE MAGNETOMETER AT MAITRI TO ONSET OF GEOMAGNETIC DISTURBANCE

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Abstract

An attempt has been made to understand the physical processes in the auroral ionosphere over MAITRI (geog. coord. 70.75°S, 52.8°E) and their response to geomagnetic disturbances. After observing the signatures of auroral ionospheric current systems on the ground magnetograms of fluxgate magnetometer, we tried to correlate these with the auroral absorption events recorded by a 30 MHz Riometer. The radio noise absorption is caused by the charged, particle precipitation in the auroral ionosphere i.e. by the secondary ionisation created in the lower ionosphere over Maitri. While passing through the region of enhanced electron density the cosmic radio noise suffers increased absorption resulting in a decrease in signal strength received by Riometer on the ground absorption events are categorized into the dawn, daytime, dusk and nighttime events and corresponding variations in the ionospheric current systems are presented here.

The X, Y and Z variations recorded by the magnetometer give clues to the direction, intensity and extent of overhead auroral currents systems.

Introduction

The Indian Institute of Geomagnetism has been operating Fluxgate Magnetometers at MAITRI (MAI with geog. coord 70.75°S, 11.75°E, geomagnetic 62.8°S, 52.8°E coord) over the past two decades. These Fluxgate Magnetometers (FM) have been recording variations in the three orthogonal components of the surface geomagnetic field, X (north- south direction), Y (east-west) and Z (vertical), in other words known as Daily Variations (DV). A Riometer (Radio Ionospheric Opacity Meter) recording the radio signal strength at ground of the natural omnidirectional 30 MHz cosmic radio noise from the Universe, was added as an experiment in 1995, but due to faulty earthing at MAI, could not yield good data for a couple of years. With the rectification of the earthing problem, the data from the Riometer (RIO) improved considerably in 1997, and by 1998 attained great reliability. The purpose of this work is to show the considerable insight into auroral physics which one obtains when the FM and RIO experiments are operated together at MAI. What the two instruments together clarify without ambiguity is that during times of magnetic Quiet (Q) MAI is a sub-auroral station which 1) experiences the magnetic effect of the southern Sq. current system and 2) does not experience any charged particle precipitation along magnetic field lines from the outer magnetosphere. With the onset of electromagnetic disturbance is geospace (caused by the arrival of energised solar wind particles in the Earth's magnetosphere), the FM and RIO signatures show dramatic change signifying 1) that the auroral zone is slowly moving over MAI in equatorward direction and 2) that MAI starts experiencing the effect of field-aligned current (fac) which as described earlier, are caused by the precipitation of energetic charged particles from the magnetosphere to the ionosphere. The Indian Antarctic station MAI is thus very suitably located for sensing Space Weather i.e. the onset of electromagnetic disturbance in Geospace, following disturbance in the interplanetary medium caused by solar disturbance. This is due to its location just outside the normal quiet-time auroral oval.

A magnetometer records the effects of integrated currents in a volume of space around the instrumets, ranging from the nearby ionosphere to the distant magnetopause. At an auroral location, most of the effects originate in the auroral electrojet (AEJ) currents in the ionospheric E region, and in field-aligned currents (fac) which flow along the geomagnetic field lines linking the ionosphere with the magnetosphere. A fluxgate magnetometer at MAI records geomagnetic field variations along the three geographic axes, X (north-south) Y (east-west) and Z (vertical). These however do not uniquely define the direction of the causative current system, because a deflection in any one direction can be due to either of two currents in two different directions. It is from the known physics that one infers the most probable direction of the current causing the magnetic disturbance. Thus in the case of the east-west magnetic variation Y, the causative current at auroral region could be in the north-south direction, or in the vertical as a field-aligned current.

The advantage of a Riometer is that at auroral locations it gives further clues on the most likely current direction. A large decrease in signal strength indicates increased absorption in the lower ionosphere (D and E regions), which in turn is caused by the secondary ionisation created in the lower ionosphere by the entry of energetic electrons from the magnetosphere along geomagnetic field lines. This is equivalent to an upward field-aligned current (fac) directed from ionosphere to the magnetosphere. Thus a large Riometer absorption event on the 30 MHz signal when accompanied by a large variation in the Y component at auroral and sub-auroral region, definitely indicates the presence of an fac over the location. Herein lies the value in operating a Riometer along with a magnetometer at auroral latitudes.

The earliest works on the high-latitude characteristics of energetic particle precipitation and ionospheric absorption were by APPLETON et. al. (1933), WELLS (1947), HEPPNER et. al. (1952) and KAISER (1955) pointed out that nighttime radio fadeouts coincided with pulsating auroras and negative magnetic bays. CAMPBELL and LEINBACH (1961) examined ionospheric absorption events which occurred simultaneously with magnetic pulsations, while HARGREAVES and F. C. COWLEY (1967), examined the latitudinal variation of auroral radio absorption events PENMAN et. al. (1979) related riometer absorption events to energetic particle precipitation events observed at L = 6.6 by geosynchronous satellites. COLLINS and KORTH (1983) and RANTA et. al. (1983) related riometer absorption to dynamic auroral substorm features, while ROSENBERG and DUDENAY (1986) studied the morphological features of riometer absorptiob at L = 4. A preliminary study of riometer observations at the Indian Antarctic station, Dakshin Gangotri was made by VENKATACHARI et. al. (1985).

The riometer has continued to be a tool till today for understanding physical processes in the magnetosphere (RANTA et. al. 1981) though now many researchers have replaced the single wide-beam instrument by ''imaging riometers'' which employ the antennae in arrays (DETRICK and ROSENBERG 1990). Imaging riometers are capable of capturing the shapes of auroral structures, and the velocity and extent of precipitating electrons, and hence yield insight into the dynamics of auroral phenomena (HARGREAVES et. al. 1997) and RANTA et. al. (1999).

Observations and Intepretations

Daytime Event

We commence our study with the daytime event of 7 Jan. 1998 (Fig.1). Daytime perturbation at a sub-auroral location like that of MAI is a rare phenomenon, and occurs only at times of magnetic disturbance. The 3 hrly Kp index values plotted as a bar diagram below, are a measure of the degree of magnetic disturbance with values descending gradually from 4 (quite Disturbed) to 2 (rather quiet); the sum Kp value of 24 given above the Y, X, Z curves indicate it to be a day of moderate disturbance. The magnetometer traces follow the Kp trend with marked disturbance seen for Kp=4, and then beyond 14 hr, quietening. The X (north-south variation) trace shows the presence of mild auroral electrojet (AE) current over MAI, as expected, tending to be westward between 09-12 UT, and clearly eastward between 13-18 UT. The Z (vertical) does not signify any special variation changes in either the intensity or the position of the AE current. The main feature about Y (east-west variation) is that its fluctuations are in concert with those of the 30 MHz RIO shown in the middle of Fig.1 e.g. the pulsations at 09:20, 11:30, 12 and 13.30 UT. These are almost simultaneous, and suggest that bunches of energetic electrons from the dayside are being precipitated along field lines above MAI, and are thus giving rise to Field-aligned current over MAI. The physical processes causing this will be discussed at the end of this paper.

Dusk Events

Fig. 2 shows absorption events in the Riometer accompanying clear variations in the Y, X, Z curves between 18-21 UT (dusk hours) of 31 Jan 1998. These are the hours when the 3 hourly Kp index attains maximum value of 4. During this interval, X (positive) shows the presence of a clear, strong eastward AE current over MAI, and is suggestive of the distant signature of a substorm occurrence in the midnight. The Z change from positive before 20 UT to negative after 20 UT, shows that the eastward AE over MAI has shifted equatorwards in position. Y does not show any large changes suggestive of strong field-aligned currents, but it fluctuates in harmony with the RIO absorption events e.g. at 18:30, 18:50 19:50 and more mildly at 21:10 UT. Fluctuations at these times are also seen in the X and Z traces. 31 Jan 1998 has a sum Kp of 180 which indicates moderate disturbance, but the interval 18-00 UT is a clearly disturbed one. Both FM and RIO traces indicate the presence of small quantas of energetic particles entering the lower ionosphere over MAI; a field aligned current sheet linking magnetosphere and ionosphere is seen in the slow, gentle decrease in Y seen during the periods of Kp =4.

Two other examples of Dust events are shown in Fig.3 and Fig.4. Both are examples of magnetically Disturbed days (sum Kp for the day exceeds 20), and the 3 hrly Kp index during the time-intervals considered attains values of 4 denoting considerable magnetic disturbance.

Fig. 3 shows the FM and RIO variations at MAI over 15-00 UT on 6 Jan 1998. X shows the clear presence of the expected dusktime eastward AE current over MAI through its positive variations. The eastward AE current appears to have intensified twice, once prior to 18 UT and the second time prior to 21 UT. The RIO signal also shows clear absorption prior to 18 UT in concert with X, suggesting the entry of energetic particles into the ionosphere from the outer magnetosphere. Mild signal absorption pulsations are seen on the RIO curve throughout the interval of 15-24 UT, suggesting that quantas of energetic particles have been entering periodically.

The variations of Y (east-west) and Z (vertical) are in phase with those of the X component. The variations in Z suggests that following the two intensifications in X around 18 UT and 21 UT, the eastward AE current moved equatorward to a position directly over MAI (indicated by Z = 0), and later moved still equatorwards of MAI. No Harang Discontinuity (HD) feature with X first sensing positive (eastward AE) then negative (westward AE) seems to have occurred; the HD phenomenon may well have occurred after 00 UT. The Y component does not show any intense field aligned currents (fac) to have occurred in a periodic manner the two throughs in Y at the same time as the intensifications in X (i.e. prior to 18 UT and 21 UT) suggest that intensifications in the fac did occur along with the eastward AE current.

The Night event in Fig. 4 is for the time-interval 16-00 UT of 20 Jan 1998. As in the earlier event in Fig.3, the X component shows two itensifications in the eastward AE current, one prior to 18 UT, and the other just before 21 UT. The Y component as for Fig. 3 varies in concert with the X component suggesting the intensification of field-aligned currents (fac) at the same times as the eastward AE currents; in fact this is seen just prior to 23 UT, when the X variation suggests the signature of a short lived westward AE current over MAI. The Z variation in Fig. however differs from the variation in Fig.3. In this case it suggests that the eastward AE current depicted by X at 18 UT has shifted equatorwards, first being located over MAI at 20:30 UT, and then shifting furthur equatorwards after that, to be located well northwards of MAI.

The RIO signal absorption for the event of Fig. 4 shows mild pulsations suggesting quantas of energetic particle precipitation from the magnetosphere into the lower ionosphere at MAI; the periodic changes in RIO arise from local power phenomena. No clear absorption events corresponding to the AE intensifications in the X component and the fac intensifications in the Y component are seen in the RIO record prior to 18 UT and 21 UT.

Dawn Events

Fig. 5 and Fig.6 represent FM and RIO for Dawn hours, the former being a specially pronounced one. The sum Kp figure of 21 for 20 Jan 1998 shows it to be magnetically disturbed, but the interval marking the event over 03-06 UT is moderately disturbed with a three hourly Kp value of 3 +; the three-hourly intervals flanking it have even lower Kp values, namely Kp = 2 over 00-03 UT, and Kp = 0 over 06-09 UT. And yet this rise to Kp = 3, has caused a clear absorption in the RIO suggesting clear field - aligned current over MAI for a brief period of time. The changes in the X and Z components are too short-lived (~1 hour) to be interpreted in terms of AE currents overhead, but are more suggestive of the signatures of a field-aligned current overhead. The Y and X changes suggest a movement of MAI from one side of a beam-type fac current, to the other side, while the Z trace shows that some amount of horizontal ionospheric current is associated with the beam, and that this horizontal band has shifted equatorwards during the event. The events on both RIO and FM are clear and smooth without pulsations, suggesting that periodic quantas of field-aligned electrons are not involved in this event.

The Dawn event of 21 Jan 1998 (Fig. 6) occurs over 06-09 UT when the three hourly Kp index touches 4+, and manifests as a clear absorption event in RIO. This event like the previous one in Fig.3, also seems associated with the similar changes in Y and X traces, suggesting that MAI has moved position under a single beam-type of fac. Z suggests too that a horizontal bar of ionospheric current was associated with the beam and that the current had some latitudinal movement towards the equator, and hence was located north of MAI. Overall the event in Fig. 6 while displaying the same characteristics as the one in Fig. 5, showed much milder variations.

The Dawn event of 7 Jan 1998 (Fig. 7) over the time-interval 00-09 UT is a spectacular one, possible because 1) is the day is a considerably disturbed one (sum Kp = 24 + and 2) the interval considered is itself very disturbed with 3 hrly Kp attaining values of 5, 6, and 4. The pronounced negative southward variation in X shows the presence of a strong intense westward AE current over MAI sufficient to have driven the magnetometer into saturation (to counteract this the sensitivity of the FM should have been changed manually but seeing the time-interval for this, namely the night hours of 03-06, this could probably not have been done). In this case on the RIO record, apart from definite long-lived signal absorption events there are superposed on these, spiky patterns indicating periodic precipitation of energetic particles from the magnetosphere to the lower ionosphere. That these precipitations are field-aligned is shown by the spiky Y variations seen in concert with the RIO variations. Z shows a similar spiky nature suggesting that for 3 hrly Kp values of 5 and 6 over 00-03 UT and 03-06 UT, the westward AE has fluctuated periodically in latitudinal position with respect to MAI taking up a northward location at times (negative Z) and a southward location at other time (positive Z).

Midnight Events

The midnight event of 17-18 Feb 1998 (from 17:40 UT of 17 Feb 1998 to 06:20 UT of 18 Feb 1998) in Fig. 8 is a very spectacular one indeed. The 3 hrly Kp value over this time interval rises from 3 through 4, 6, 7 (at 00-03 UT), and thereafter slowly decreases to 5 and 40. With the onset of severe disturbance from 21 UT of 17 Feb 1998, the sum Kp value moves from 190 to 33 (very disturbed on 18 Feb 1998). We consider the X variation first. MAI is clearly in the auroral oval, and sees the positive X signature of the eastward AE current over 18-00 UT; after midnight the negative signature of the westward AE current is seen. The Y variations show the clear presence of field-aligned current over MAI, both in extended sheet form (large-period Y change), as well as periodic quantas of charged particles precipitating from magnetosphere to ionosphere (short period fluctuations). The large negative variation suggests that prior to midnight, the eastward AE was located well polewards of MAI; after midnight, the westward AE current was still located polewards of MAI. A location for the AE currents polewards (southwards) of MAI is very surprising for high 3 hrly Kp values of 4+, 6-, 7-, 5+ as occurred during this periods. All 3 components Y, X, Z show the clear presence of short period pulsations and these are faithfully repeated in the RIO absorption signal. Owing to the thickness of the RIO trace (this noisy records always occurs at MAI during very high wind velocities typical of Antarctica), it is difficult to correlate the RIO signal as well. These small period fluctuations clearly point out to periodic fluxes of incoming enegetic particles from the magnetosphere into the ionosphere over MAI. The large 3 hrly Kp indices on this night seem to be associated with this type of repeated precipitation events rather than with any large-period precipitation events typical of sheet type fac.

The remaining 3 night events are of a different type in which the 3 hrly Kp values remain in the vicinity of 3 and 4. The X trace in Fig.9 for 29-30 Jan 1998 clearly shows that MAI has mooved from being under an eastward AE current between 21-00 UT (positive X), to being under a strong westward AE current from 00-09 UT. The negative Z variation during 00-09 UT shows that this AE current is clearly located equatorwards (north) of MAI, for Kp values in the field-aligned currents which must have accompanied the westward AE current, except during two long period variations around 03-04 UT and around 06:30-07 UT. These are clearly repeated as pronounced signal absorption in the RIO record, and yet another one is repeated in both RIO and FM at 22:30 UT. Clearly energetic electrons precipitated into the lower ionosphere over MAI during these 3 intervals, causing significant outward field-aligned currents. The short period pulsations in the FM records (marked on the Z trace as a, b, c, d) are clearly seen on the RIO absorption record between o4-06 UT.

Fig. 10 shows the midnight event for 11-12 Feb. 1998, from 1600 UT of 11 Feb. 1998 (with sum Kp = 24) to 03 UT of 12 Feb 1998 (with sum Kp = 19). We start with an understanding of the X variation. The positive X prior to 21 UT clearly shows that MAI was under the influence of the dusk side eastward AE current; after 21 UT, the station comes under the influence of the westward AE current (negative X). The clear negative Z variation after 21 UT indicates that the AE current is clearly equatorwards of MAI for Kp values of 3 and 4. It is interesting that variations in the Y, X and Z components are all in concert with slight time-lags, i.e. at ~16:30 UT then at ~20:30 UT when sharp variations in all 3 magnetic components suggest that MAI passed under the well-known auroral feature called the Harang Discontinuity, at ~23UT, at ~00 UT, and again around 01 UT. The last 4 of these are accompanied by clear absorption in the RIO signal and clearly correspond to energetic particle precipitation events. A general decrease in the RIO signal level is seen over the entire interval 16 UT-03 UT.

The last event considered in this work is the midnight one for 8-9 Feb 1998, from 19 UT-05UT (Fig.11). Plannet Earth has moved from magnetically quieter conditions on 8 Feb 1998 (Kp = 13) to more Disturbed conditions on 9 Feb 1998 (Kp=210). The Y, X and Z variations indicate much the same auroral conditions, as were obtained in the earlier event in Fig.10, possible because the 3 hrly Kp values have similar values of 3,4 etc. in both cases. The X variation in Fig.11 again shows MAI to have experienced the eastward AE current effect (positive X) in the dusk hours, and the westward AE current effect (negative X) after midnight hours. The Z variation indicates that during the hours following 21 UT, the westward AE current flowed equatorward of MAI (negative Z) i.e. for the disturbed Kp values of 40. The Z variation shows sharp, short lived positive values over 23:10 to 23:40 UT, suggesting that for this brief interval of time the station sensed the strong north-south component of the Harang Discontinuity, or that the westward AE current had a short lived poleward excursion. This feature in Z is reflected in the X and Y components as well, but no corresponding major change is seen in the RIO absorprion. This absence of any feature on the RIO record suggests that this event on the Y, X, Z traces is connected more with the north-south directed Harand Discontinuity, than with any major field-aligned current system. Similar to the event in Fig. 10, the RIO absorption pattern shows a general signal decrease over this whole time interval with periodic quantas of precipitation of energetic electrons from the outer magnetosphere manifesting in the periodic small-intensity absorption patterns seen on the RIO curves.

Conclusions And Discussions

The above-discussed observations and interpretations make it quite clear that the RIO and the FM when operated together in auroral locations enable one to have good insight into the physical electromagnetic processes at work above MAI station.

As far as local time characteristics are concerned, this present study seems to bring out the following features :-

1) Daytime event (In Fig.1) referring to RIO and FM phenomena in the 09-18 UT sector, suggests that these are not very energetic, and are more in the nature of a drizzle of particles along field lines, from the dayside magnetosphere to the ionosphere.

2) Dusk events (Fig.2, 3,) from the RIO and FM variations show that these are more energetic than the daytime one with clear pronounced RIO absorption patterns, suggesting considerable field aligned particle precipitation. While the auroral electrojet signatures (both westward and eastward currents) on the X and Z components are clear, the Y variations caused by field aligned currents are rather subdued.

3) Dawn events (Fig. 5, 6, 7) are seen as long-period RIO absorption event. When Kp is moderately disturbed (values of 3, 4), but the RIO takes up a spiky, high frequency character when Kp values are high (i.e. values of 5, 6 etc.). These periodicities seen in RIO are also repeated in the X, Y, Z traces.

4) Midnight events (Fig. 4, 8, 9, 10, 11) are without doubt, the most energetic in local time.

This is understandable because the main deposition of solar wind energy into the Earh's magentosphere occurs in the nightside hours through the tail. This flow of solar wind plasma is continuously accelerated through E x B forces by the changing dawn-to dusk convection electric field (E) in the presence of the Earth's ambient magnetic field. Sometimes the E x B acceleration forces are strong enough to let the plasma intrude into normally closed magnetic field line regions, with energy which they can gain only in the nightside region i.e. the magnetospheric central plasma sheet in the equatorial plane penetrates into normally forbidden closed field lines in earthward direction. Not only are clear signature of the westward and eastward auroral electrojet currents seen on the X and Z traces, but large-scale variations on the Y component show the presence of substantial field-aligned currents during midnight events.

The simultaneous presence of clear, pronounced absorption events on the RIO record for midnight events show that the Y variations are indeed due to field-aligned currents (particle precipitation events) and are not due to north-south ionospheric currents. The RIO events, and the Y, X, Z variations are of a spiky type for the high Kp values of 5, 6, 7 etc. while for Kp values of 4, they are of a broad, long-period type. This would suggest that during highly disturbed intervals, quantas of hot electrons periodically precipitate into the auroral ionosphere from the nightside magnetosphere. The case of the midnight event of 17-18 Feb 1998 requires some elaboration. It was mentioned while discussing the event in Sec. 2.4 that positive Z variations during very high Kp values of 6, 7 etc (i.e. very disturbed conditions), when the AE currents should be located well equatorwards of MAI, was unusual. Deeper thought suggests that for these very high 3 hrly Kp values of 6, 7, 5 etc. the AE currents not only move equatorwards but broaden in latitudinal extent i.e. the auroral oval occupies a large range of latitudes both north and south of MAI. Such a situation would explain the positive Z in Fig. 8 during a period of clearly westward AE (negative X from 00 UT onwards).

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REFERENCES

APPLETON E. V., R NAISMITH and G. BUILDER (1933), 'Ionospheric investigations at high latitudes', Nature, 132, p. 340-341.

CAMPBELL W.H. and H. LEINBACH (1961), "Ionospheric absorption at times of auroral and magnetic pulsations', J. Geophy. Res. 66, P.25.

COLLINS P. N. and A. KORTH (1983) "Auroral radio absorption and the westward travelling surge', Planet. Space Sci., 31, p. 1373.

DETRICK D. L. and T. J. ROSENBERG (1990), 'A phased array radiowave imager for studies of cosmic noise absorption', Radio Sci., 25, p. 325.

HARGREAVES J. K., S. BROWNE, H. RANTA, A. RANTA, T. J. ROSENBERG and L. DETRICK (1997), "A study of substorm associated nightside spike events in auroral absorption using imager Riometers at South Pole and Kilpisjarvic, J. Atmosph. Terres. Phys., 59, p. 853.

HARGREAVES J. K. and F. C. COWLEY (1967), 'Studies of auroral radio absorption events at three magnetic latitudes-I occurrence and statistical properties of the events, Planet. Space Sci., 15, p. 1571.

HEPPNER J. P., E.C. BYRNE and A.E. BELON (1952), 'The association of absorption and Es ionisation with aurora at high latitudes', J. Geophys. Res. 57, p. 121-134.

[illegible]R T. R. (1955), 'Radio investigation of aurorae and related phenoemana', pp. 156-173 in 'The Airglow and the Aurora' ed. E.B.Armstrong and A. Dalgarno, Pergamon Press, London.

PENMAN J. M., J. K. HARGREAVES and C.E. MCILIWAIN (1979), 'The rekatuib between 10 to 80 KeV electron precipitation observed at geosynchoronous orbit and auroral radio absorption observed with Riometers', Planet. Space Sci., 27, 445
RANTA H., A. RANTA and J. K. HARGREAVES (1999), 'Small-scale structure of ionospheric absorption of cosmic noise during pre onset and sharp onset phases of an auroral absorption substorm', Geophysica, 35, (1-2).

RANTA A., H. RANTA, T. J. ROSENBERG, U. WEDEKEN and P. STAUNING (1983), 'Development of an auroral absorption substorm : studies of substorm related events in the afternoon-early evening sector', ROSENBERG T.J. and J.R. DUDENAY (1986), 'The local time substorm and seasonal dependence of electron precipitation at L = 4 inferred from Riometer measurements', J. Geophys. Res., 91, 12032.

VENKATACHARI R., A. SEN GUPTA, G.K. RANGARAJAN and L. D'CRUZ, 'Riometer observations at Antarctica', Ind. J. Radio and Space Phys., 14, p. 157.

WELLS H. W. (1947), 'Polar radio disturbances during magnetic bays', Terres. Magn. And Atmos. Electr., 52, p. 315-320.

FIGURE CAPTIONS

Fig. 1 On 7th Jan. 1998, there is magnetic disturbance (sum Kp = 24 +) Y, X and Z variations are rather weak. Auroral absorption (both of large period type and short-period pulsation type) shows dayside energetic electron precipitation between 09-15 UT, where the 3 hrly Kp values are 4-and 3-.

Fig. 2 The dusk event of 31 Jan 1998 between 15-00 UT ; (sum Kp = 180) shows moderate disturbance. A strong eastward AE is seen in X, weakening after 18 UT. The change in Z from positive to negative occurs because MAI has rotated from under the eastward current system to westward current system. Clear auroral absorption is seen with the increasing magnetic activity with Kp = 4 + with spikes indicating quantas of charged particle precipitation. Similar spikes recorded in Y indicate the presence of fac.

Fig. 3 A dusk event of 6th Jan 1998 (sum Kp = 23+) between 15-00 UT, shows in phase variations in Y, X and Z, RIO absorption at 18 UT indicates the precipitation of charged particle. The station has been under strong eastward AE at 18 and 21 UT (positive X) and positive Z shows that the AE current was equatorward of MAI.

Fig. 4. A night event of 20th Jan 1998 (sum Kp = 21-) shows that the variations in Y, X and Z are in phase. X-variations indicates strong eastward AE at 23 UT and change in Z indicates that MAI moved in position, from eastward AE to westward AE current. Absorption seen in phase with Y variations.

Fig. 5. A dawn event on 20th Jan 1998 (sum Kp=210) shows short lived variations in X & Z. A smooth absorption is seen in RIO-signal, indicating that periodic quantas of field aligned electrons are not involved in this event. The westward AE in X-is seen during Kp = 3 +; the negative Z indicaes that AE is equatorward of MAI.

Fig. 6. A dawn event of 21st Jan 1998 (sum Kp=230) shows rise of Kp to 4+ accompanied by a clear RIO-absorption. Similar changes in Y & X suggesting that MAI has moved under a single beam type of fac. Z-variation shows the position of the eastward AE.

Fig. 7. The dawn event of 7th Jan 1998 (sum Kp=24+) is a highly disturbed one. There are large and rapid fluctuation seen in phase in Y, X & Z traces and the RIO record. The long period absorption and the rapid fluctuation in Y clearly indicates the precipitation of energetic charged particle over MAI. These are associated with fac seen from Y fluctuations. X-shows the presence of a strong westward AE; the rapid fluctuations in Z shows periodic movement of the WAE equatorward and poleward with respect to MAI.

Fig. 8 Midnight event on 17th - 18th Feb 1998 (sum Kp=190 and 33-) shows rapid and sharp variations in Y, which indicates the clear presence of fac over MAI and similar short period RIO absorption shows particle precipitation associated with fac. X-signature shows the clear presence of EAE in dusk sector & WAE in dawn sector (00-06 UT). For these high Kp values of 4, 6, 7, 5 the auroral oval must have broaden out to occupy latitudes both south and north of MAI. This would explain the Z-signature negative before midnight and mildly positive after midnight.

Fig. 9. Night event on 29th - 30th Jan 1998 (sum Kp = 15 + & 260) shows variations in Y & RIO between 03-09 UT are in concert showing the presence of fac during absorption events (long period and short period). X-shows the presence of fac during absorption event (long period and short period). X-shows the presence of strong westward AE current from 00-09 UT. From Z-variations the positions of WAE is known to be equatorward of MAI.

Fig. 10 A midnight event on 11th-12th Feb. 1998 (sum Kp=24+& 19-) showing the periodic and sharp absorptions in RIO, which are in concert with Y associated with fac. Variations in X-show the MAI position in a region of EAE to WAE at 21

UT. After 21 UT, WAE was situated equatorward of MAI.

Fig. 11 A midnight event on 8th -9th Feb. 1998 (sum Kp=130 & 210) shows variations in Y-indicating the presence of fac around midnight and X-shows EAE around 2230 UT and WAE after 2230 UT. RIO absorption events are seen as periodic and short lived with some local electrical disturbances (spikes). Z-variations are mainly a negative one and shows that WAE is equatorward of MAI.

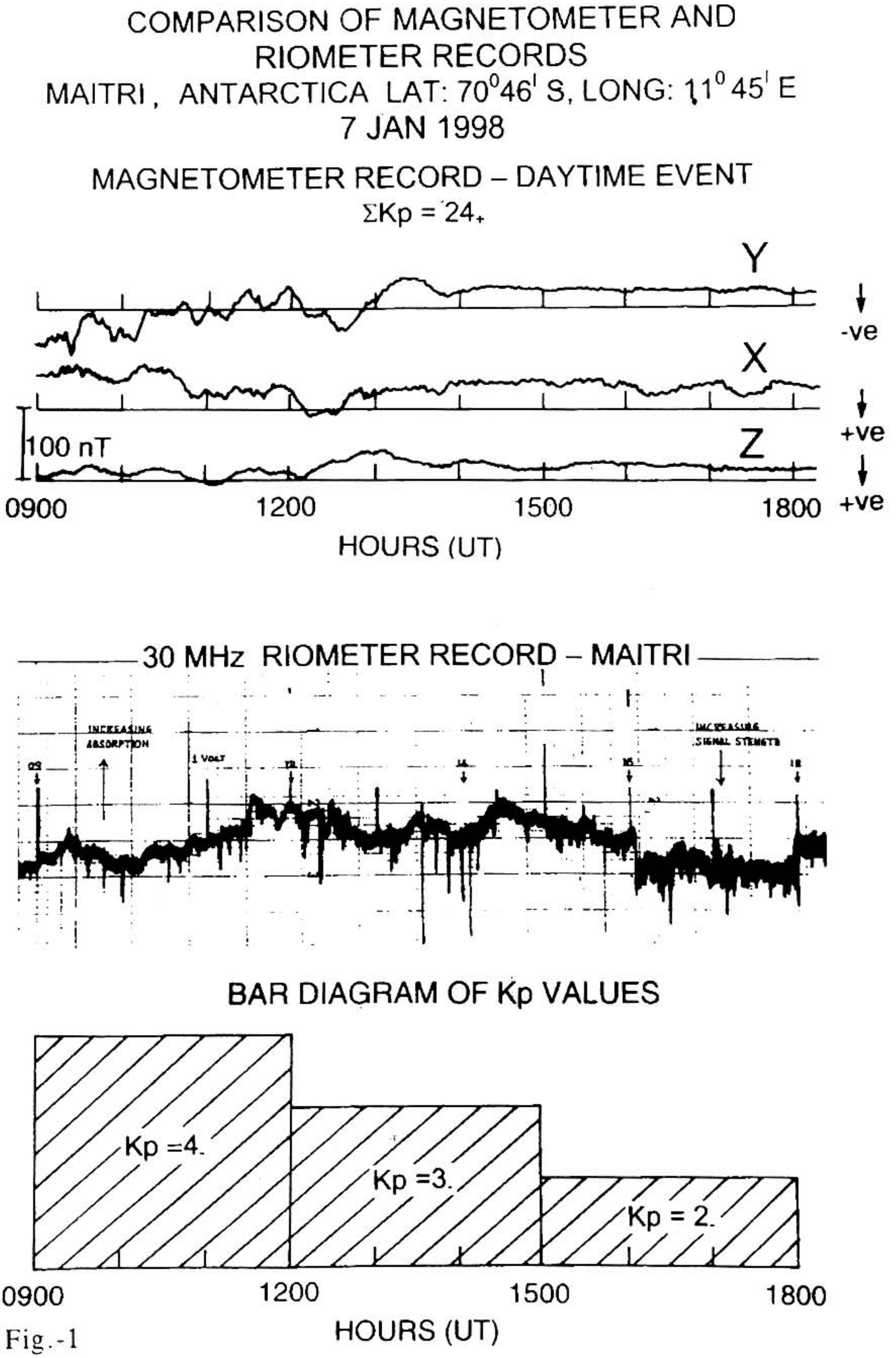
COMPARISON OF MAGNETOMETER AND
RIOMETER RECORDS
MAITRI , ANTARCTICA LAT: 70°46' S, LONG: 11° 45' E
7 JAN 1998
MAGNETOMETER RECORD – DAYTIME EVENT
ΣKp = 24+
Y
-ve
X
+ve
Z
+ve
100 nT
0900
1200
1500
1800
HOURS (UT)
30 MHz RIOMETER RECORD – MAITRI
INCREASING ABSORPTION
1 VOLT
BAR DIAGRAM OF Kp VALUES
Kp =4.
Kp =3.
Kp = 2.
0900
1200
1500
1800
HOURS (UT)

Fig.-1

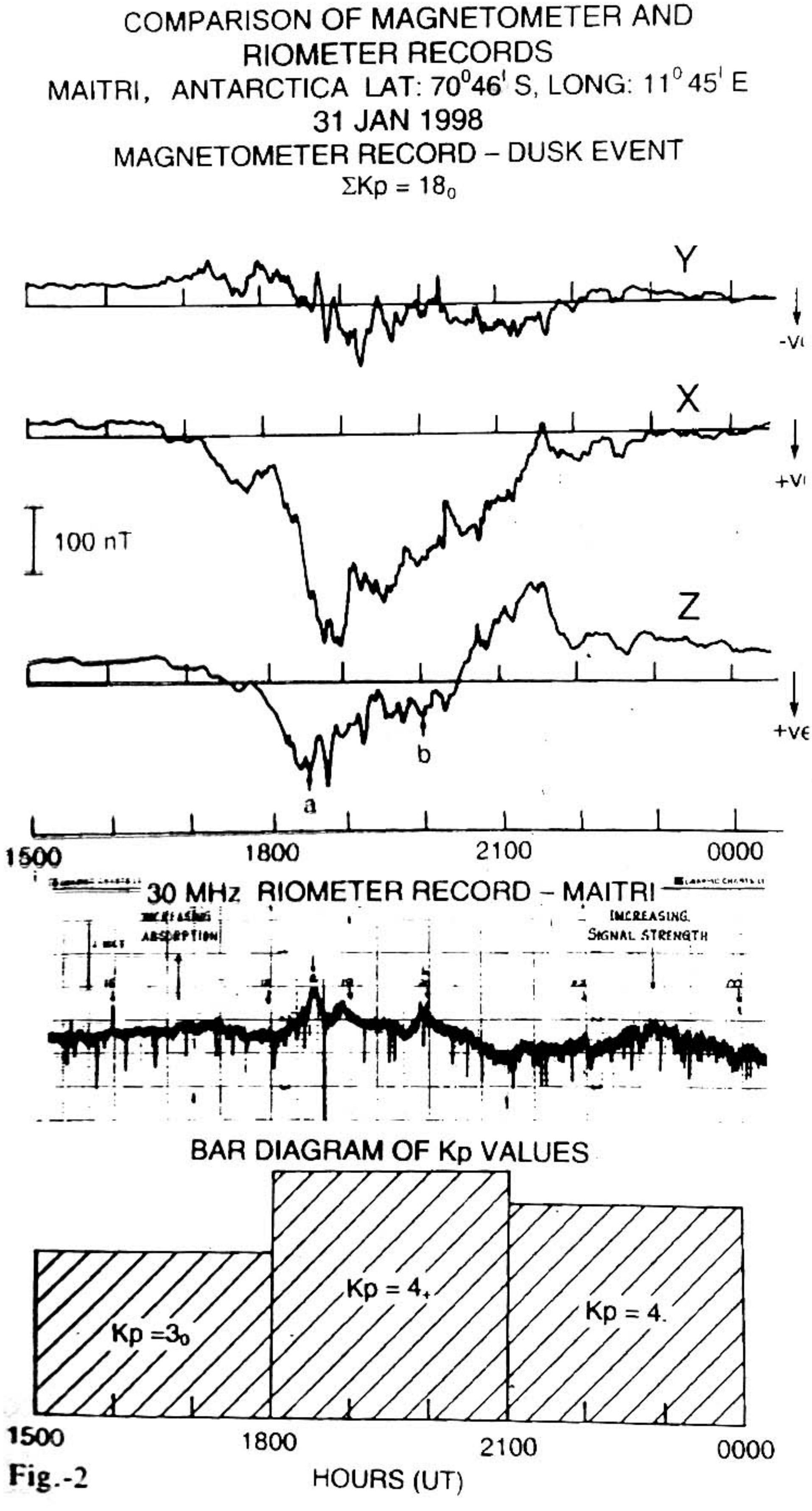
COMPARISON OF MAGNETOMETER AND RIOMETER RECORDS
MAITRI, ANTARCTICA LAT: 70°46' S, LONG: 11°45' E
31 JAN 1998
MAGNETOMETER RECORD – DUSK EVENT
ΣKp = 18₀
Y
X
Z
100 nT
a
b
1500
1800
2100
0000
30 MHz RIOMETER RECORD – MAITRI
INCREASING ABSORPTION
INCREASING SIGNAL STRENGTH
BAR DIAGRAM OF Kp VALUES
Kp =3₀
Kp = 4₊
Kp = 4₋
1500
1800
2100
0000
HOURS (UT)

Fig.-2

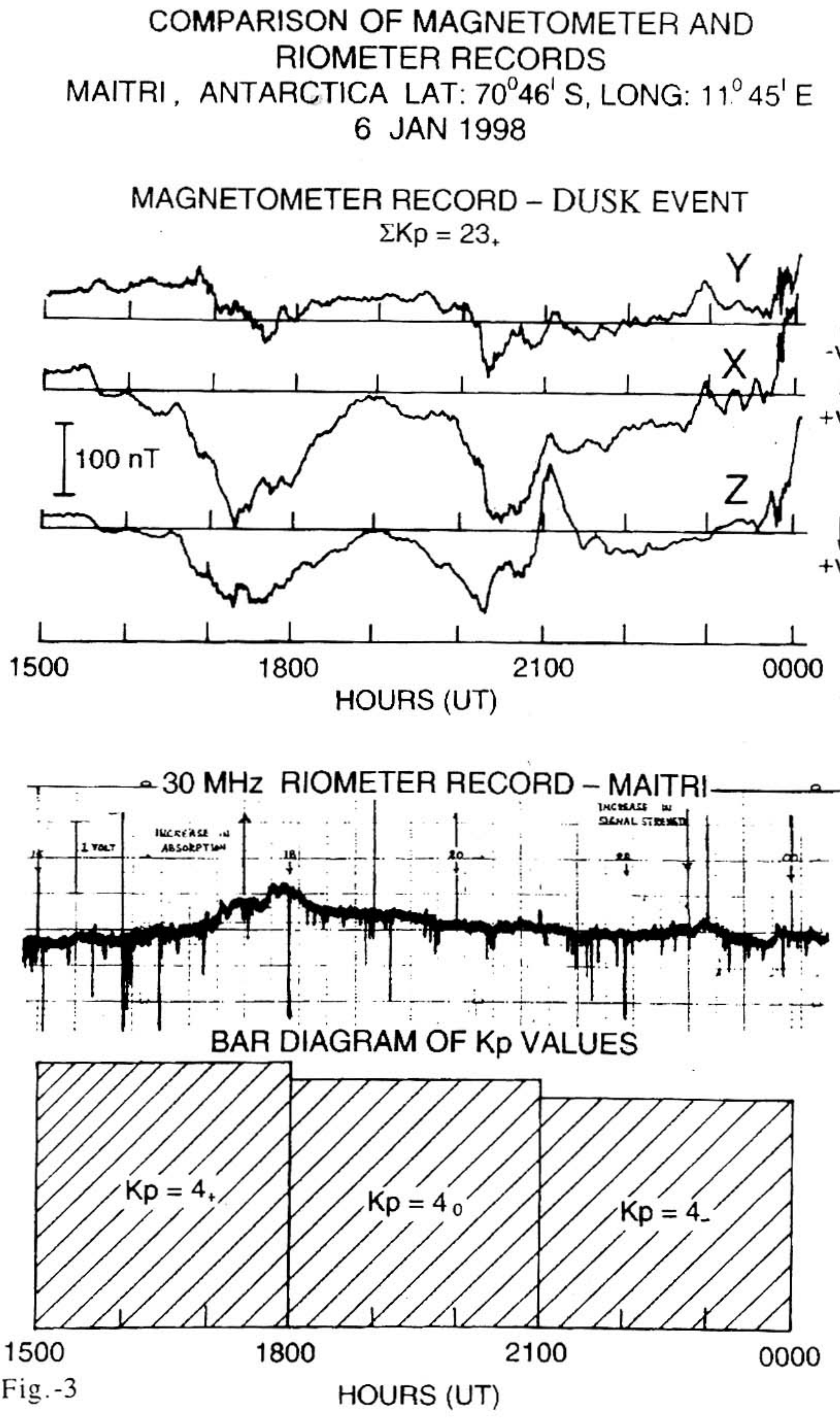
COMPARISON OF MAGNETOMETER AND RIOMETER RECORDS
MAITRI , ANTARCTICA LAT: 70°46' S, LONG: 11°45' E
6 JAN 1998
MAGNETOMETER RECORD – DUSK EVENT
ΣKp = 23+
Y
X
Z
-ve
+ve
+ve
100 nT
1500
1800
2100
0000
HOURS (UT)
30 MHz RIOMETER RECORD – MAITRI
1 VOLT
INCREASE IN ABSORPTION
INCREASE IN SIGNAL STRENGTH
BAR DIAGRAM OF Kp VALUES
Kp = 4+
Kp = 4 0
Kp = 4-
1500
1800
2100
0000
HOURS (UT)

Fig.-3

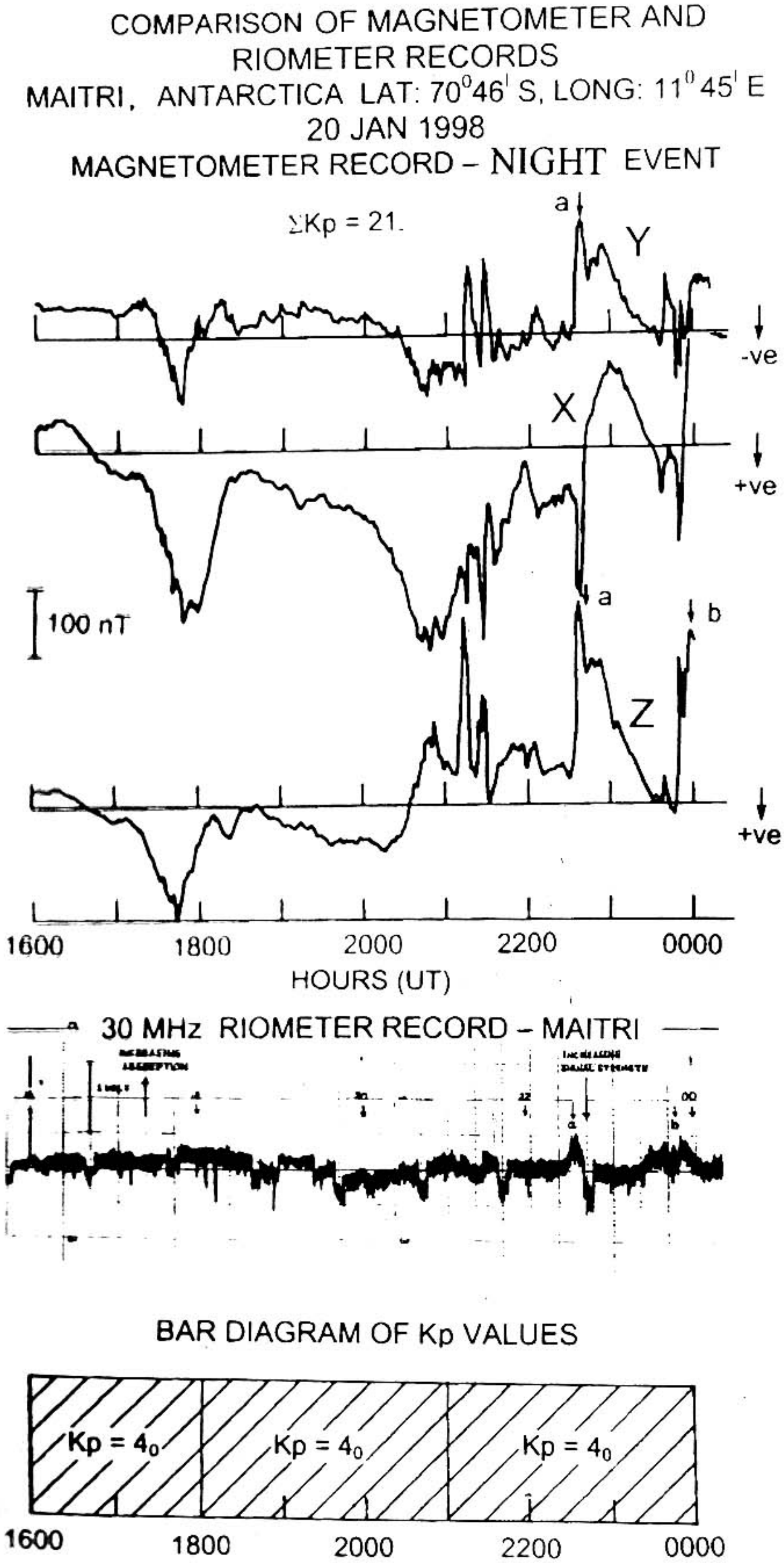
COMPARISON OF MAGNETOMETER AND
RIOMETER RECORDS
MAITRI, ANTARCTICA LAT: 70°46' S, LONG: 11°45' E
20 JAN 1998
MAGNETOMETER RECORD – NIGHT EVENT
ΣKp = 21.
a
Y
-ve
X
+ve
a
b
100 nT
Z
+ve
1600
1800
2000
2200
0000
HOURS (UT)
30 MHz RIOMETER RECORD – MAITRI
BAR DIAGRAM OF Kp VALUES
Kp = 4₀
Kp = 4₀
Kp = 4₀
1600
1800
2000
2200
0000
HOURS (UT)

Fig.-4

COMPARISON OF MAGNETOMETER RECORD AND RIOMETER RECORDS
MAITRI – ANTARCTICA LAT: 70°46' S, LONG: 11°45' E
20 JAN 1998 $\Sigma Kp = 21_0$

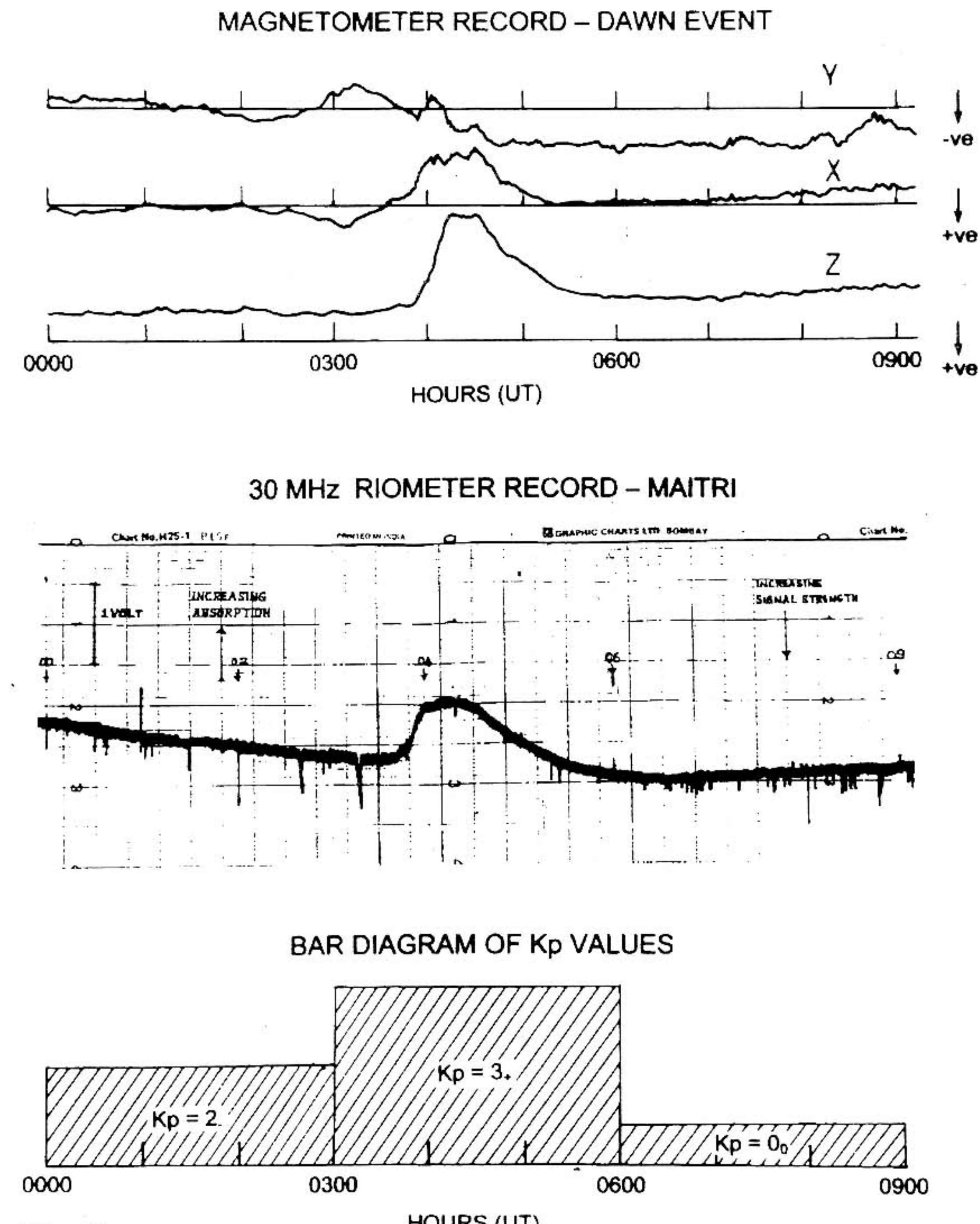

Fig.-5

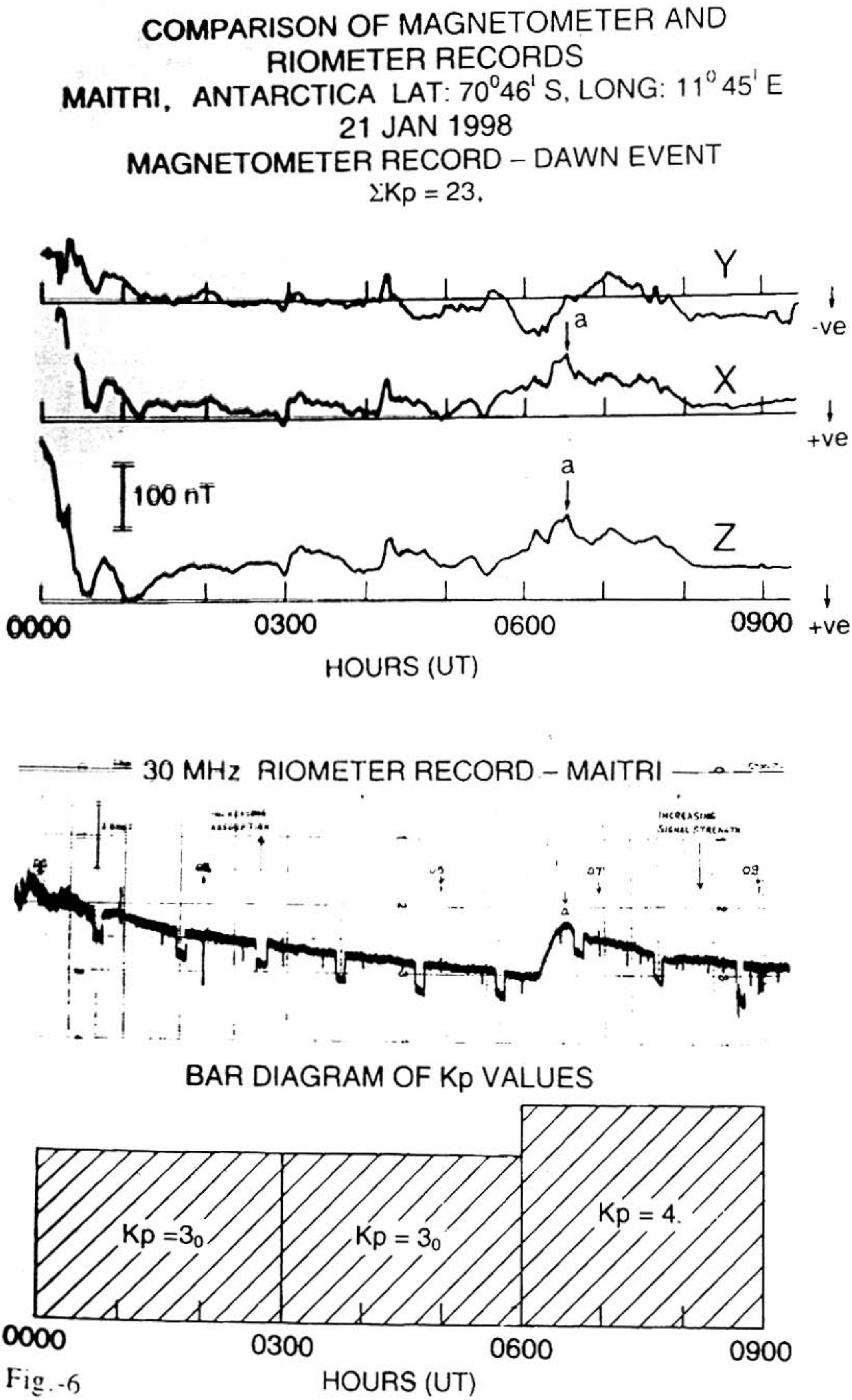
COMPARISON OF MAGNETOMETER AND
RIOMETER RECORDS
MAITRI, ANTARCTICA LAT: 70°46' S, LONG: 11°45' E
21 JAN 1998
MAGNETOMETER RECORD – DAWN EVENT
ΣKp = 23.
Y
-ve
a
X
+ve
100 nT
a
Z
+ve
0000
0300
0600
0900
HOURS (UT)
30 MHz RIOMETER RECORD – MAITRI
BAR DIAGRAM OF Kp VALUES
Kp = 3₀
Kp = 3₀
Kp = 4.
0000
0300
0600
0900
HOURS (UT)

Fig.-6

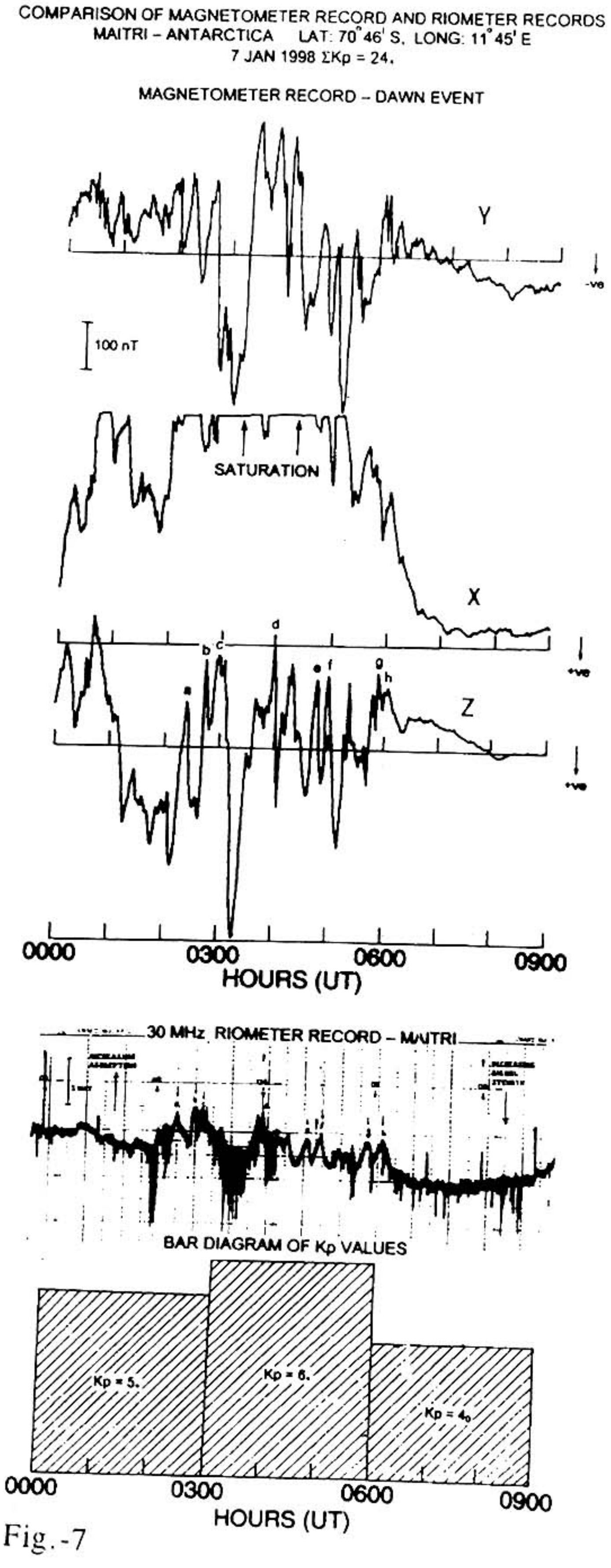
COMPARISON OF MAGNETOMETER RECORD AND RIOMETER RECORDS
MAITRI – ANTARCTICA LAT: 70°46' S, LONG: 11°45' E
7 JAN 1998 ΣKp = 24.
MAGNETOMETER RECORD – DAWN EVENT
Y
-ve
100 nT
SATURATION
X
+ve
a
b
c
d
e
f
g
h
Z
+ve
0000
0300
0600
0900
HOURS (UT)
30 MHz RIOMETER RECORD – MAITRI
BAR DIAGRAM OF Kp VALUES
Kp = 5.
Kp = 6.
Kp = 4o
0000
0300
0600
0900
HOURS (UT)

Fig.-7

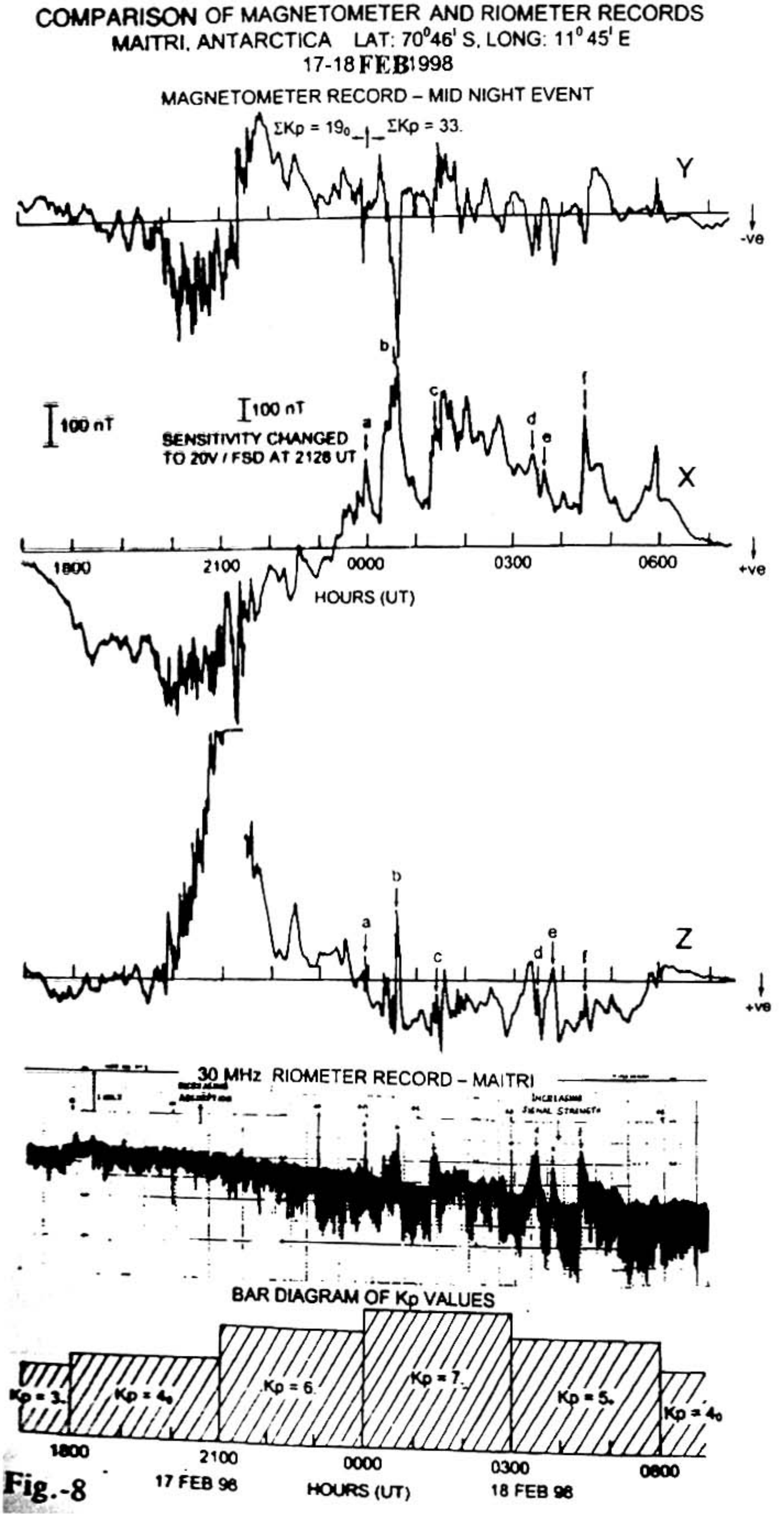
COMPARISON OF MAGNETOMETER AND RIOMETER RECORDS
MAITRI, ANTARCTICA LAT: 70°46' S, LONG: 11°45' E
17-18 FEB 1998
MAGNETOMETER RECORD – MID NIGHT EVENT
ΣKp = 19₀
ΣKp = 33.
Y
-ve
100 nT
100 nT
SENSITIVITY CHANGED TO 20V / FSD AT 2128 UT
X
1800
2100
0000
0300
0600
+ve
HOURS (UT)
Z
+ve
30 MHz RIOMETER RECORD – MAITRI
BAR DIAGRAM OF Kp VALUES
Kp = 3.
Kp = 4₀
Kp = 6.
Kp = 7.
Kp = 5.
Kp = 4₀
1800
2100
0000
0300
0600
17 FEB 98
HOURS (UT)
18 FEB 98

Fig.-8

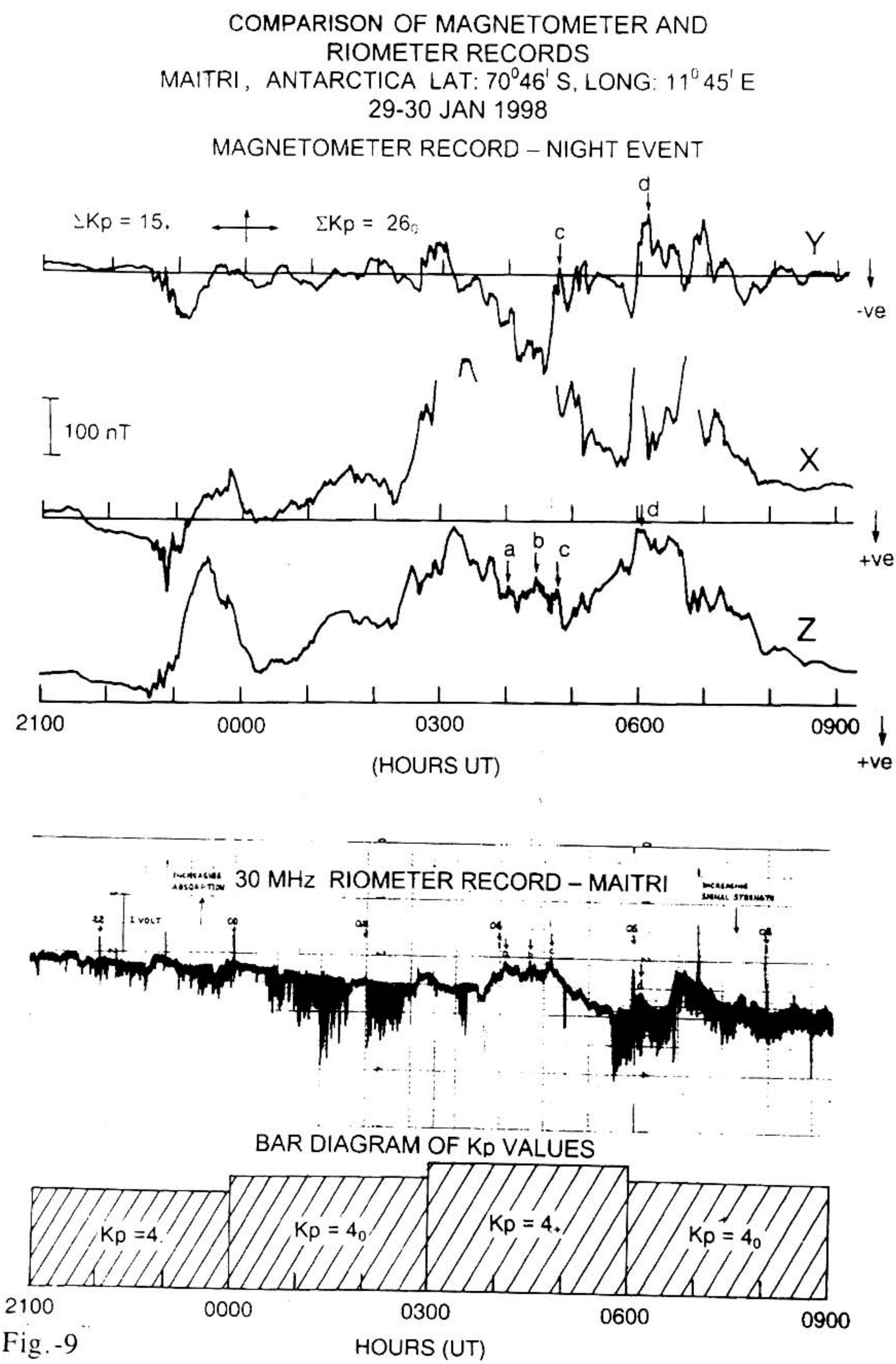
COMPARISON OF MAGNETOMETER AND
RIOMETER RECORDS
MAITRI, ANTARCTICA LAT: 70°46' S, LONG: 11°45' E
29-30 JAN 1998
MAGNETOMETER RECORD – NIGHT EVENT
ΣKp = 15.
ΣKp = 26₀
d
c
Y
-ve
100 nT
X
d
a
b
c
+ve
Z
2100
0000
0300
0600
0900
+ve
(HOURS UT)
30 MHz RIOMETER RECORD – MAITRI
1 VOLT
BAR DIAGRAM OF Kp VALUES
Kp = 4.
Kp = 4₀
Kp = 4+
Kp = 4₀
2100
0000
0300
0600
0900
HOURS (UT)

Fig.-9

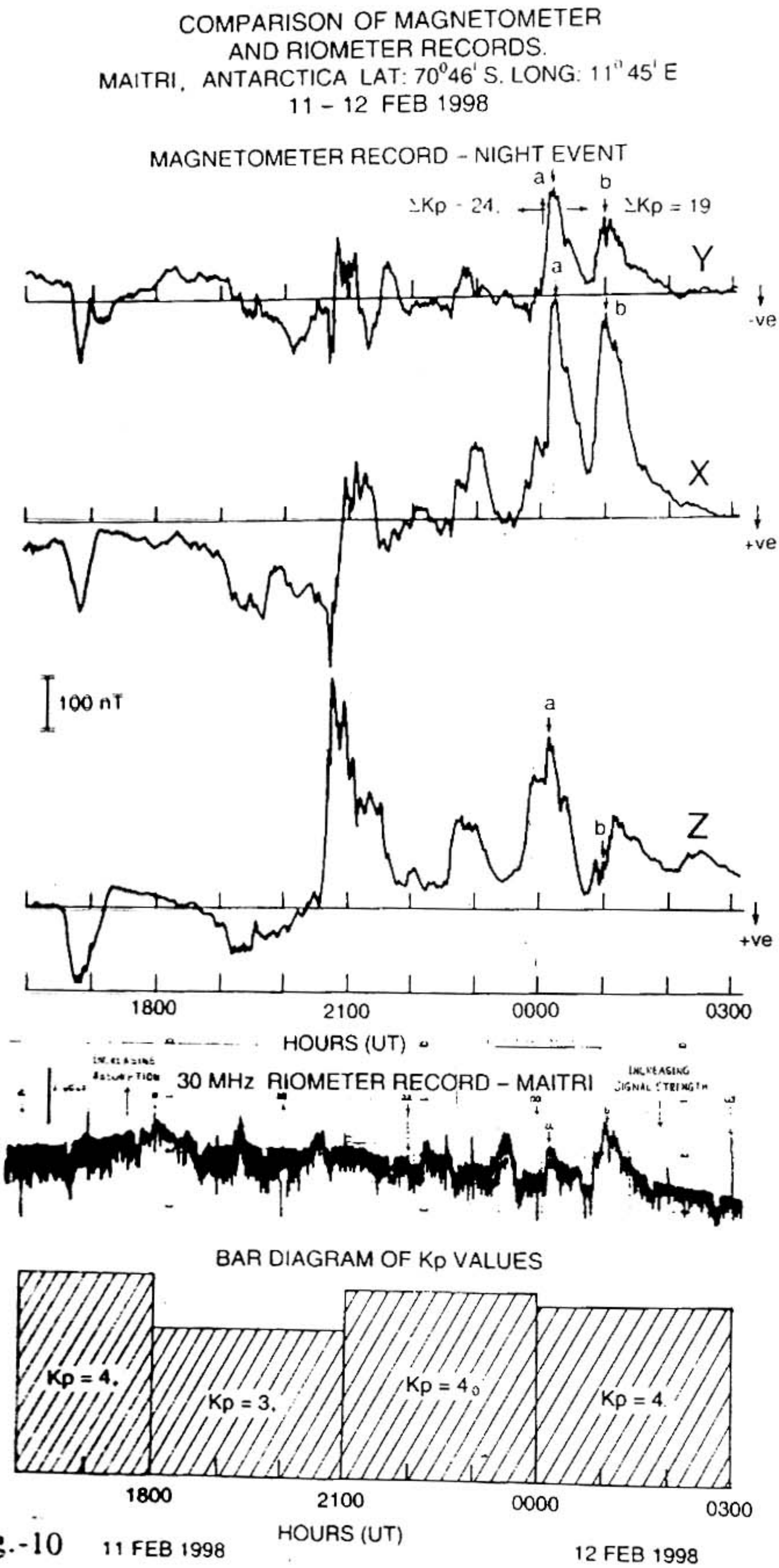
COMPARISON OF MAGNETOMETER
AND RIOMETER RECORDS.
MAITRI, ANTARCTICA LAT: 70°46' S. LONG: 11°45' E
11 - 12 FEB 1998
MAGNETOMETER RECORD - NIGHT EVENT
ΣKp = 24
ΣKp = 19
a
b
Y
-ve
X
+ve
100 nT
Z
+ve
1800
2100
0000
0300
HOURS (UT)
30 MHz RIOMETER RECORD - MAITRI
BAR DIAGRAM OF Kp VALUES
Kp = 4.
Kp = 3.
Kp = 4₀
Kp = 4
1800
2100
0000
0300
HOURS (UT)
11 FEB 1998
12 FEB 1998

Fig.-10

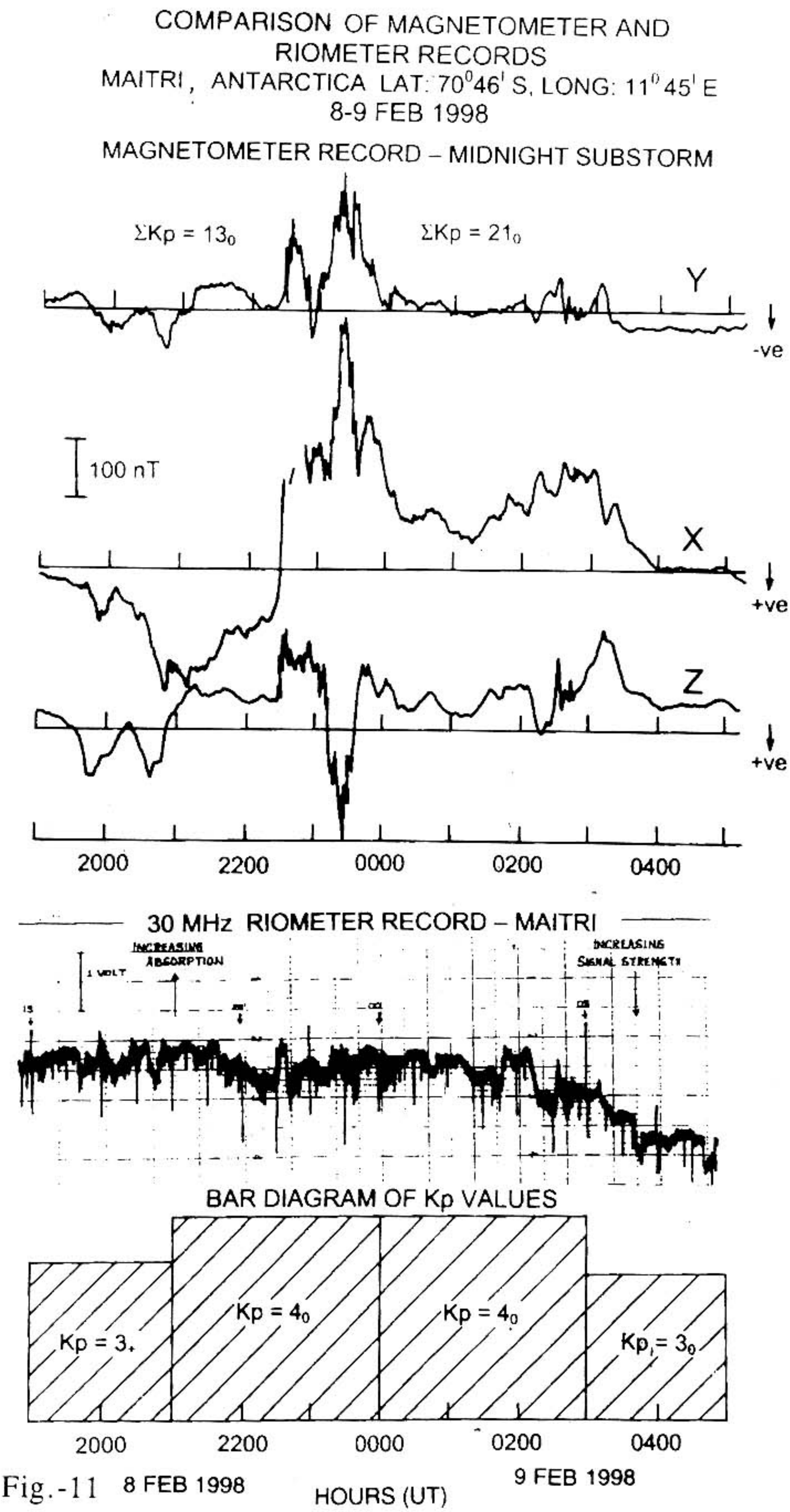
COMPARISON OF MAGNETOMETER AND
RIOMETER RECORDS
MAITRI, ANTARCTICA LAT: 70°46' S, LONG: 11°45' E
8-9 FEB 1998
MAGNETOMETER RECORD – MIDNIGHT SUBSTORM
ΣKp = 13₀
ΣKp = 21₀
Y
-ve
100 nT
X
+ve
Z
+ve
2000
2200
0000
0200
0400
30 MHz RIOMETER RECORD – MAITRI
INCREASING ABSORPTION
1 VOLT
INCREASING SIGNAL STRENGTH
BAR DIAGRAM OF Kp VALUES
Kp = 3+
Kp = 4₀
Kp = 4₀
Kp = 3₀
2000
2200
0000
0200
0400
8 FEB 1998
HOURS (UT)
9 FEB 1998

Fig.-11