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Geomagnetic Storm Effects at Equatorial Electrojet Stations

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ABSTRACT
The studies of the geomagnetic H and D data from the Kyushu University network of stations has confirmed the suggestions made by Rastogi et al (2001) that during the magnetic storms, the deviations of horizontal field (H) and the eastward field (Y) are related by $\Delta Y/\Delta H = \sin(\Psi\text{-}D)$, where Ψ is the dipole declination and D is the ground (dip) declination at the station.

INTRODUCTION

Magnetic storms at low and middle latitudes are characterized by a sudden increase of the horizontal component of the geomagnetic field (H) called Storm Sudden Commencement (SSC) followed by an above normal H field for few hours called Initial Phase (IP) and decrease of H by 50-300 nT within 5-6 hours called Main Phase (MP) and later a slow recovery of H field to its normal value in a couple of days called Recovery Phase (Moos 1910; Chapman 1918 and Vestine et al. 1947). Chapman (1951) found that unlike the enhancement of solar quiet daily variation of H at midday at equatorial electrojet stations, the disturbance daily variations of H at Huancayo did not show any abnormality and were similar to those at mid-latitude stations, with a dawn maximum and dusk minimum.

Sugiura & Chapman (1960) made a monumental study of the quiet (Sq) and disturbed (Sd) day variations, Disturbance daily (SD) and storm-time (Dst) variations of the geomagnetic field at a number of stations around the world. Disturbance daily variation of H at Huancayo was found to be normal, as observed at other mid-latitude stations. The solar quite and disturbed daily variations of declination were found to be consistent with latitude and reversed on crossing the equator. Akasofu & Chapman (1961) explained the absence of storm effects on declination suggesting that the effects of radiation belts on the equatorial ring current are axially aligned. Iyemori (1990) assumed that the ring current flows in a direction parallel to the dipole equatorial plane to derive the symmetrical and antisymmetrical components in H and Y fields during magnetic storm periods. Rastogi (1992) showed that the storm-time variations of horizontal (H) field as well as of the westerly declination (Dw) at Kodaikanal and Alibag followed remarkably well the corresponding variation of equatorial ring current index (Dst) developed by Sugiura (1964). There were large decreases of Dw at Kodaikanal as well as at Alibag during the main phase of the storm. Both the daily mean values of H and D at Kodaikanal decreased monotonously with increasing daily mean value of Dst index suggesting increasing westward field with increasing disturbance at a station with mean westerly declination itself. Rastogi (1996) described the magnetic disturbance effects in H and Y fields at the network of twelve stations along the Indo-Russian longitude sector. The disturbance effects were negative in H and positive in Y at all of the stations in this sector. Further, the disturbance effects in H decreased while those in Y increased with increasing latitude of the stations, for this 75^0E geographic longitude sector.

Later, it was found that the disturbance daily as well as storm-time variations of D (easterly) at Huancayo were similar to those of westerly declination at Kodaikanal (Rastogi 1993). This presented a puzzle regarding the cause of disturbances in declination at low latitude. Rastogi, Winch & James (2001) found that the disturbance effects in Y field at Kakioka and Alibag are opposite in nature even though the mean declination are westerly at both stations, but the difference between dipole declination (Ψ) and dip declination (D) is positive ($+13.0^0$) at Kakioka and negative (-6.4^0) at Alibag. It was argued that the ring current particles follow the dipole lines of force at magnetosphere altitude and the hourly deviations are computed with respect to mean dip declination. It was shown that the simultaneous values of ΔY and ΔH during the magnetic disturbance at any station follows the relation $\Delta Y/\Delta H = \sin(\Psi\text{-}D)$. The longitudinal inequalities of storm behavior in declination were suggested as due to the different longitudinal variations of dip and dipole declinations. The main idea of the present paper is to test the above hypothesis with the data from stations distributed at different part of the world.

DATA AND ANALYSIS

The Kyushu University has been operating portable digital magnetometers recording H, D and Z fields at different equatorial stations around the world since 1993. The analysis presented in this paper is based entirely on these data from Kyushu University. The stations with their geographic and geomagnetic coordinates are listed in Table 1.

The contours of easterly magnetic (dip) declination (D) in degrees and the difference between easterly dipole declination (Ψ) and magnetic declination (D) in degrees are shown in Fig.1(a). The counters of Ψ alone are not shown as these are simple functions of geographic longitude/ latitude with respect to the position of the north dipole; Ψ represents the direction of dipole (78.98^{0}N and 70.89^{0}W) as seen from the stations.

Referring to the contours of magnetic declination (D) on geographic latitude versus longitude coordinates it is noted that the isolines of D are aligned almost north– south in Pacific and American longitudes while these are aligned nearly east-west in European, African and Asian longitudes. Over equatorial and low latitude regions upto about 180^0 E, variation of D is very flat, only 5^{0}W to 5^{0}E. In the Central Pacific, D is highly easterly about 10^{0}E, over Eastern Pacific to Western Atlantic there is a very sharp variation from about 10^{0}E to about 20^{0}W.

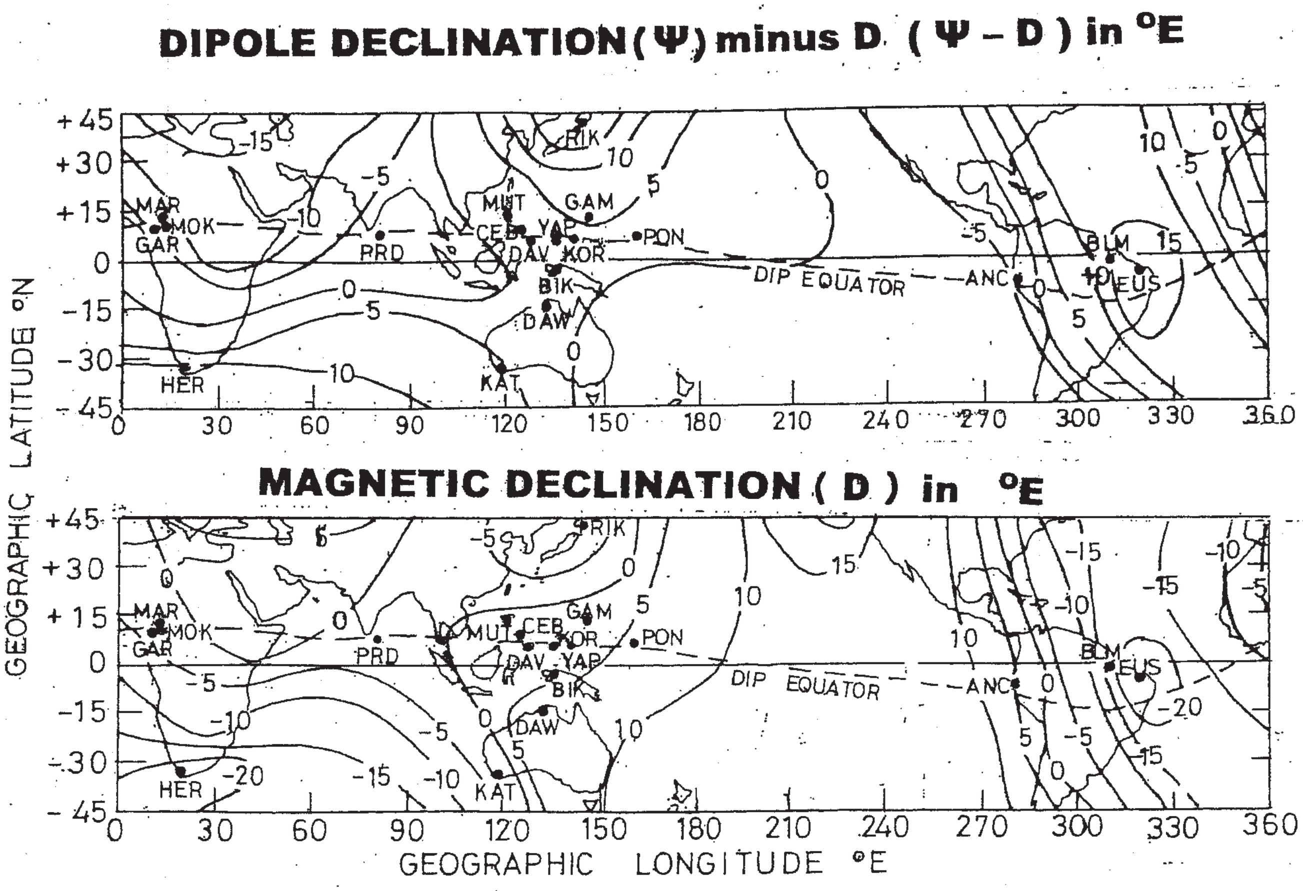

Figure 1a. Contours of magnetic (dip) declination (D) and the difference between dipole declination (ψ) and D on the geographic map of world

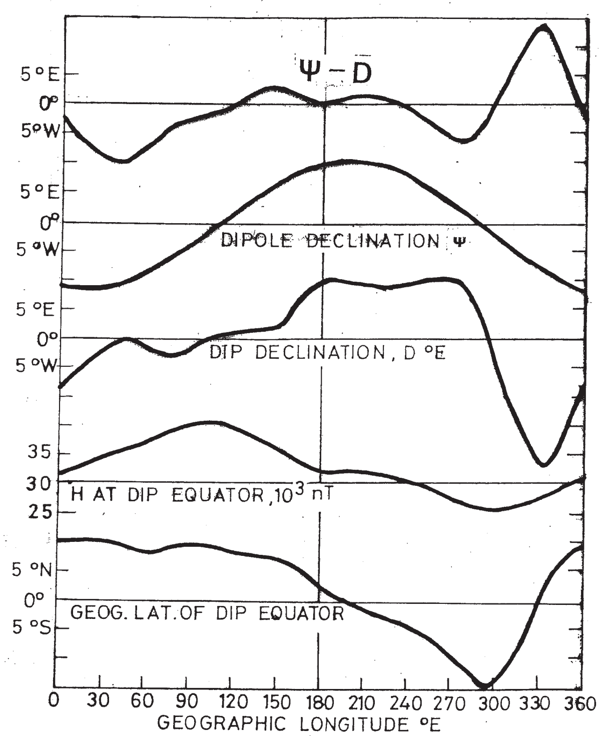

Figure 1b. Variations with geographic longitude of (i) the geographic latitude of the magnetic equator, (ii) the magnetic field (H) at ground over the dip equator, (iii) the magnetic (dip) declination at ground, D, (iv) the dipole declination at magnetospheric regions, Ψ and (v) the Ψ-D.

Referring to contours of Ψ-D, its value along the dip equator is lowest in East Africa (about 12^0W) and highest in Eastern Brazil (about 15^0E). The Kyushu University network of stations is very significant because the geomagnetic data from the above two important locations were not available so far in any data centers. It is seen from the figure that Ψ-D varies over a wide positive and negative values along the dip equator itself.

In Fig. 1(b) are shown the variations of following parameters with respect to geographic longitude (i) the geographic latitude of the dip equator, (ii) the magnitude of H field at ground over the dip equator, (iii) the magnetic (dip) declination (D) at dip equator (iv) the dipole declination (Ψ) at magnetospheric region over dip equator and (v) the difference of dipole and dip declinations over the equator (Ψ-D). It is seen that the dip equator is northward at 10^o geographic latitude around $0\text{-}30^o$ i.e. in the West Africa, with increasing longitude it slowly approaches the geographic equator and crosses it around 200^o longitude i.e. mid-Pacific, deviates to southernmost latitude of about 14^o between 290^o and 300^o longitude, i.e. Central Brazil, deviates very sharply northward over Eastern Brazil. The magnetic field (H) is highest exceeding 40,000 nT around 100^o longitude and is lowest around 300^o longitude. The dip declination is again abnormally large westward exceeding 20^o in Eastern Brazil region. Dipole declination is zero around 290^o longitude

Table 1. List of stations with their geographic and geomagnetic (dipole) coordinates.

Station	Code	Geog. Lat. θ^0N	Geog. Long. Φ^0E	Geom. Lat. ^{0}N	Geom. Long. ^{0}E	Inclina-tion I^0N	Mag. Decli. D^0E	Geom. Decli. Ψ^0E	$(\Psi\text{-D})^0$E
Ancon	ANC	-12.1	-77.0	+1.6	354.7	0.4	0.4	1.1	+0.7
Belem	BLM	-1.2	-48.5	+8.1	25.9	3.8	-19.6	-4.2	+15.4
Eusebio	EUS	-3.9	-38.4	-0.1	34.5	-13.0	-21. 6	-5.9	+15.7
Garou	GAR	+9.2	+13.2	+1.3	85.1	-4.9	-1.1	-11.0	-9.9
Mokolo	MOK	+10.4	+13.5	+1.3	84.8	-1.6	+0.8	-11.0	-11.8
Maroua	MAR	+10.4	+14.2	+2.3	86.0	-1.7	+0.7	-11.0	-11.7
Hermanus	HER	-34.3	+19.2	-42.1	82.7	-66.0	-24.1	-11.0	+13.1
Peredinia	PRD	+7.3	+80.6	-0.9	151.9	-2.3	-2.6	-5.3	-2.7
Cebu	CEB	+10.4	+123.9	+0.9	195.3	+6.1	0.4	+2.9	+2.5
Davao	DAV	+7.0	+125.4	-1.3	196.8	-1.5	0.3	+3.0	+2.7
Yap	YAP	+9.3	+138.5	+0.5	209.7	+3.2	+1.3	+5.4	+4.1
Pohnpei	PON	+7.0	+158.3	+0.3	229.4	+3.1	+6.2	+8.3	+2.1
Guam	GAM	+13.6	+144.9	+5.7	215.8	+12.3	+1.5	+6.9	+5.4
Ettaiyapuram	ETT	+9.0	+78.0	-0.2	149.8	+2.4	-2.7	-5.4	-2.7

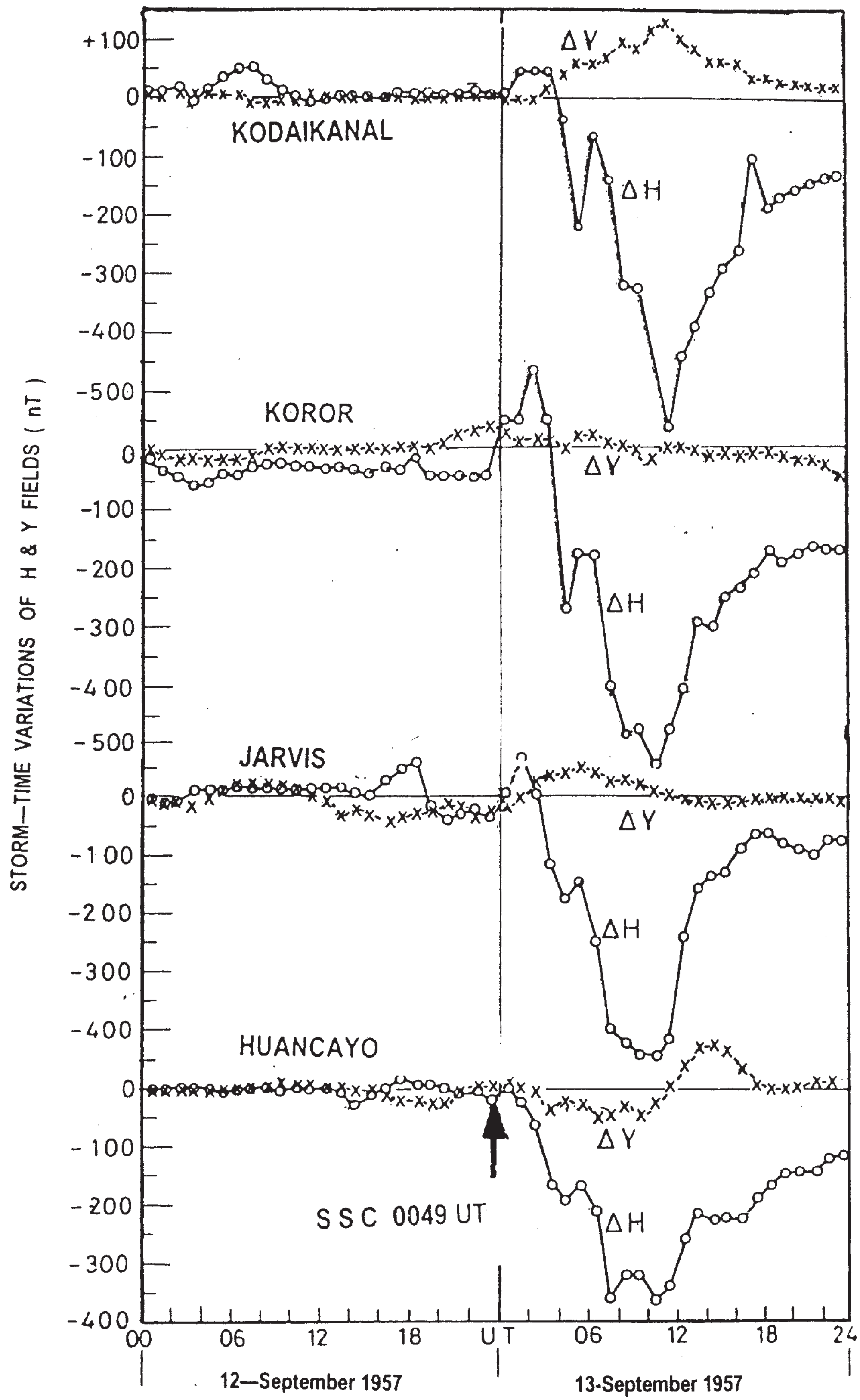

Figure 2. Storm-time variations of H and Y fields at equatorial electrojet stations during the magnetic storm of 13 September 1957

because the north dipole is taken to be 71°W longitude (289°E) and is zero again at around 110° longitude. The value of Ψ-D is around 10°W in East Africa and about 15°E in East Brazil. Thus, the eastern region of Brazil presents very abnormal distribution of geomagnetic field.

The permanent equatorial observatories whose data are available in the World Data Center are Addis-Ababa (ψ-D = -9.3°), Kodaikanal (ψ-D = -2.9°), Koror (ψ-D = +2.6°), Jarvis (ψ-D = +1.4°) and Huancayo (ψ-D = -4.5°). These are too few to study the effect of dip and dipole declinations on magnetic storms. Kyushu University network of observatories provides a much better spatial distribution and fills the gaps in many regions; these stations are marked in Fig. 1a. There are stations in Central Africa (MAR, MOK, GAR) at 75° longitude (PRD), a cluster of stations in East Indies, in West Peru (ANC) and in East Brazil (BLM and EUS). It was therefore decided to study the effect of magnetic storms on H and D component at all available equatorial electrojet stations.

There was a major magnetic storm starting at 0049 UT on 13 September 1957, the minimum value of Dst index was -427 nT at 1030UT on 13 September 1957. The storm-time variations of H and Y fields at equatorial stations Huancayo, Jarvis, Koror and Kodaikanal are shown in Fig. 2. The storm-time variations of H field were almost similar at all these stations, although the maximum decrease of H was not the same at different stations. The range of H field during disturbance at Huancayo was only –350 nT around 1130 UT (0630 LT), at Jarvis the decrease was about –450 nT around local midnight, at Koror the decrease was –550 nT around 19 hr local time and at Kodaikanal it was –570 nT around 16 hr local time. It is not certain that the magnitude of main phase storm depressions is dependent on the local time of station.

The storm-time variations of Y field were very different at different stations, there was only very small change of Y at Koror and Jarvis but ΔY was positive and high (about 100 nT) at Kodaikanal and Huancayo.

Next, the storms, which occurred during 1993-2001 and available at Kyushu network stations, were identified. The H and D variations from two days before the magnetic storm to two days after the magnetic storms were studied separately for stations in American, African and Asian sectors.

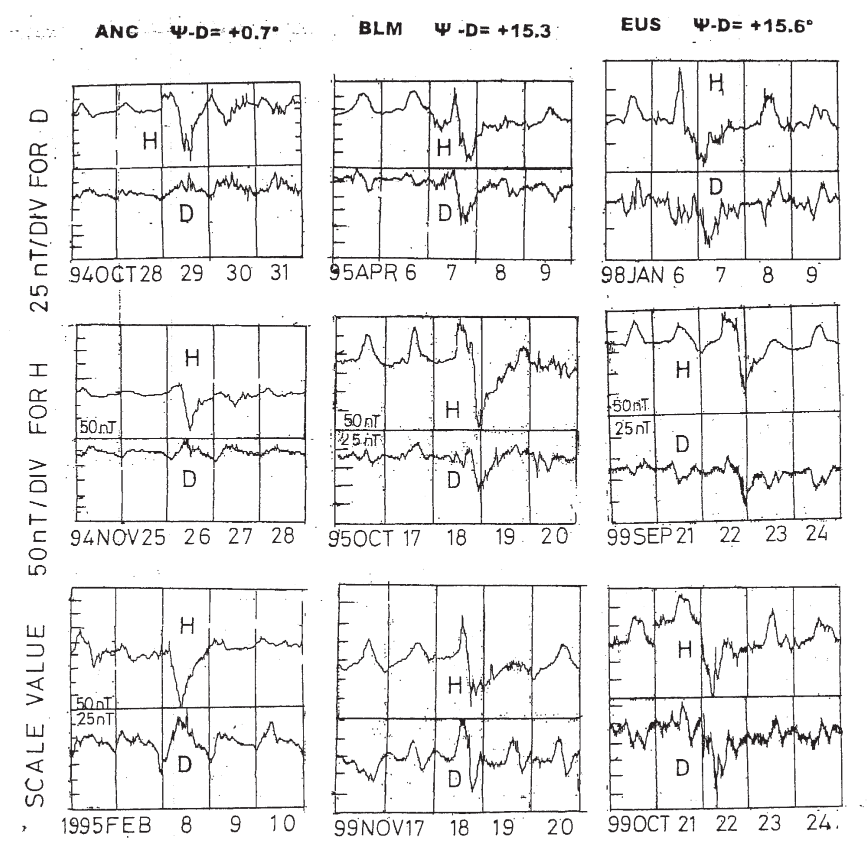

Figure 3a. Reproduction of H and D magnetograms associated with magnetic storms at equatorial stations in American sector.

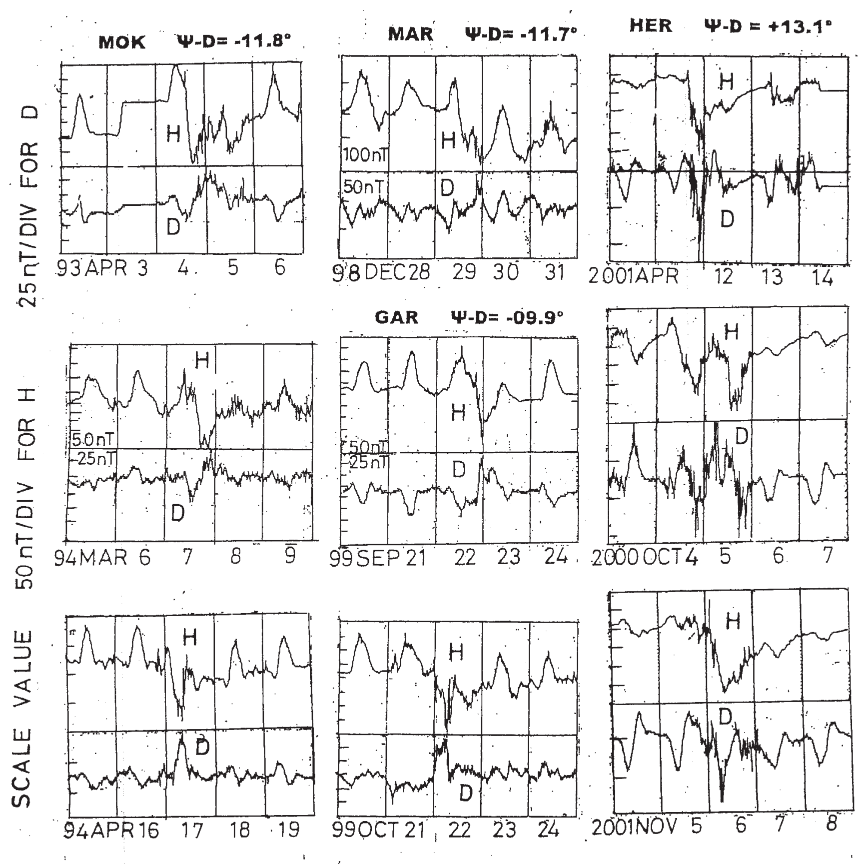

Figure 3b. Reproduction of H and D magnetograms associated with magnetic storms at equatorial stations in African sector.

Fig.3(a) shows magnetograms at stations in American sector. It may be noted that the scales of Y field and H field are not same. Equatorial electrojet stations chosen are Ancon (ANC) in Peru with I = 0.4^0 and ψ-D = 0.7^0E, Belem (BLM) in Central Brazil with I = 3.8^0 and Ψ-D = 15.3^0E and Eusebio (EUS) in Eastern Brazil with I =-13.0^0 and ψ-D = 15.7^0E. At Ancon where ψ-D is very small (0.7^0), the decrease of ΔH (200nT) was accompanied by very small increase of Y compared to the daily variations on other days. At Belem with large ψ-D (+15.3^0), the decrease of H during storms was very faithfully reproduced in the large decrease of ΔD, showing ΔY/ΔH as positive. At Eusebio with large positive value of ψ-D (+15.7^0), the decrease of H was accompanied with large decrease of D. At Belem and Eusebio, ΔD was about one quarter of ΔH, such that $\sin^{-1}(\Delta Y/\Delta H)$ is about 15^0 roughly equal to ψ-D at these stations.

In Fig. 3 (b) are shown storm magnetograms at African stations, Mokolo (MOK), Maroua (MAR) and Garou (GAR) in Central Africa all with high negative ψ-D (about -10^0) and at Hermanus (HER) in South Africa with high positive ψ-D (about 13^0). One can see that on 17 April 1994, a decrease of H by about 300 nT at Mokolo was accompanied with simultaneous increase of D by 70 nT giving $\sin^{-1}(\Delta Y/\Delta H)$ is -13.5^0 corresponding to a value of ψ-D of -11.8^0 at the station. Similar increase of D associated with the decrease of H during the storms on 7 March 1994 and 4 April 1993 were also noticed. At Maroua and Garou too the decrease of H with storminess were associated with significant increase of D. On the other hand at Hermanus with high positive ψ-D, the storm-time decrease of H was accompanied with simultaneous decrease of D during each of the storms shown here.

Fig.3c shows storm magnetograms at Asian stations, Peredinia (PRD) in Sri Lanka, at Pohnpei (PON) and at Guam, the ψ-D values for all stations are very small. At Peredinia the decrease of H associated with storminess were accompanied with small increases of D. At Pohnpei, decrease of H accompanied similar decreases of D. At Guam with ψ-D = 5^0, the decreases of D were significant compared to the decrease of H field. So, in general, for all stations where ψ-D is very small, the storm effects on D component are not significant.

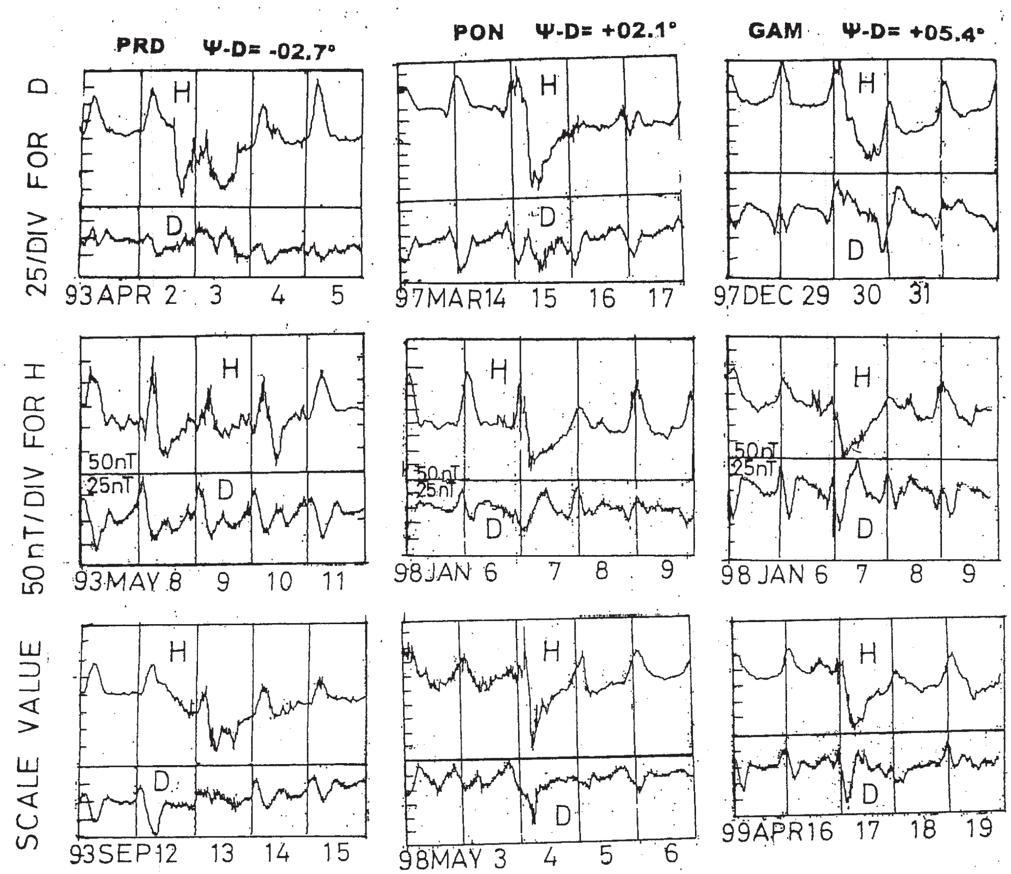

Figure 3c. Reproduction of H and D magnetograms associated with magnetic storms at equatorial stations in Asian sector.

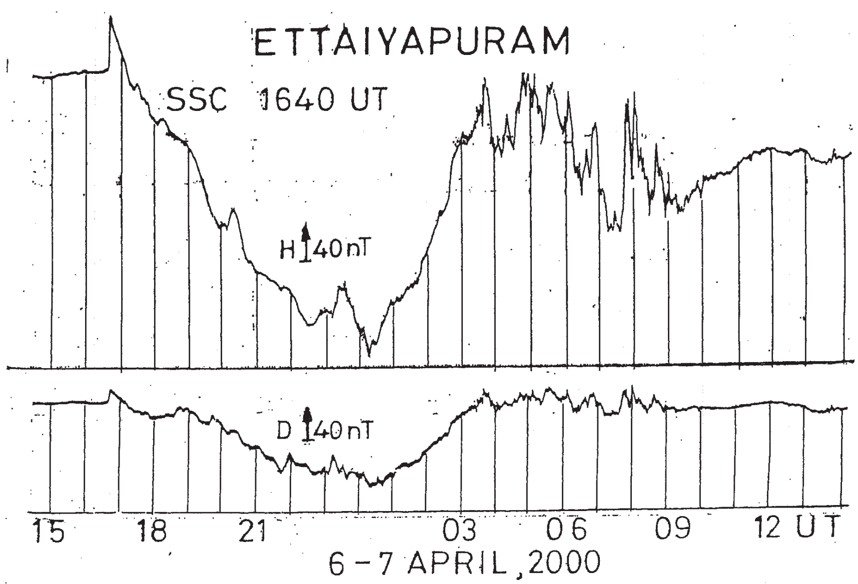

Figure 4. Reproduction of magnetograms at the equatorial electrojet station Ettaiyapuram during the magnetic storm of 6-7 April, 2000

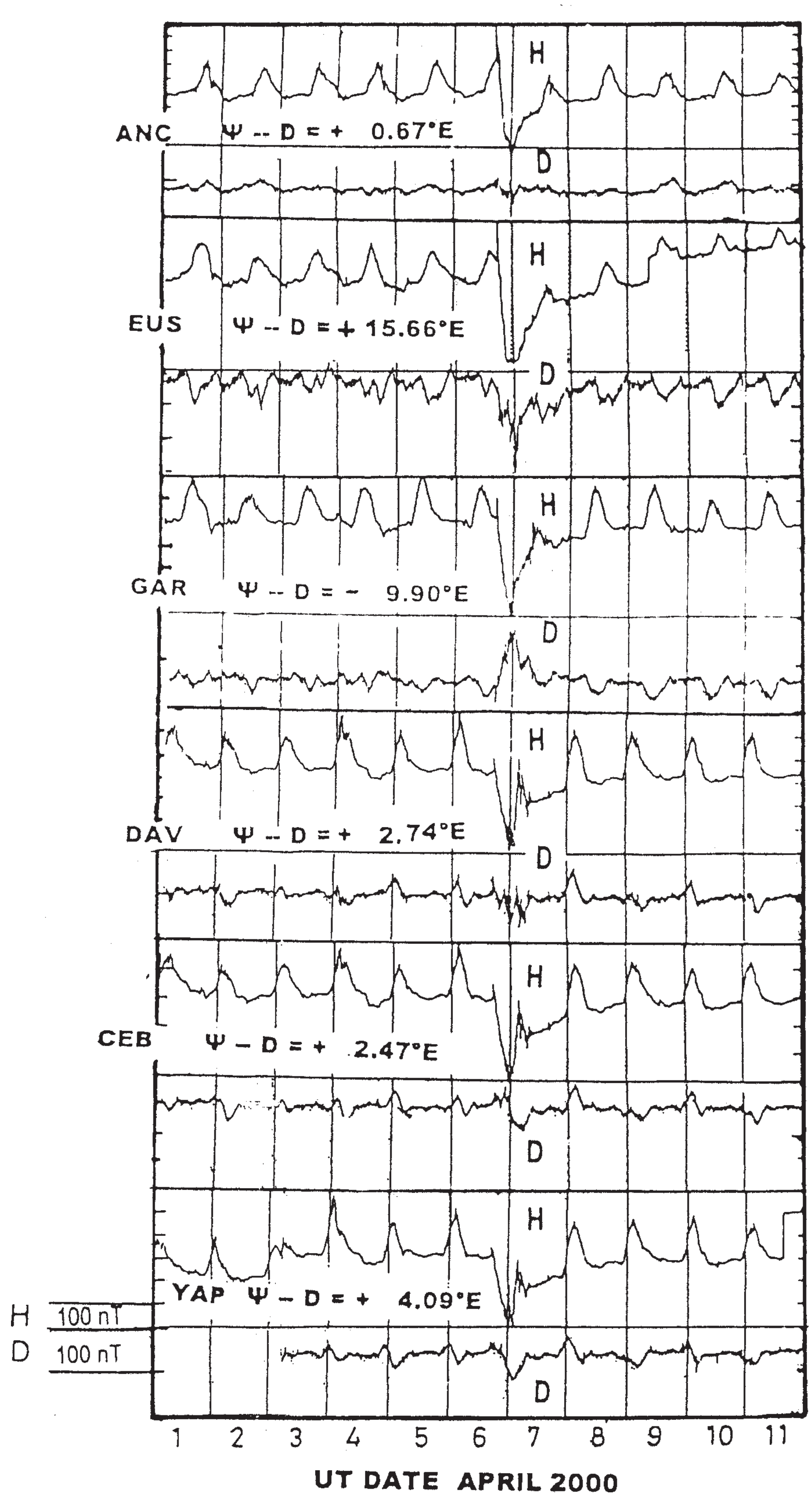

Figure 5. Magnetogram tracing at equatorial electrojet stations of Kyushu University network a few days before the storm to a few days after the storm (6-7 April 2000)

A major storm occurred on 6-7 April 2000 with a SSC at 1640 UT and the minimum Dst of –314 nT on 6 April 2002. This event was preceded by a halo CME on 4 April 2000, a C9.7 class solar flare and the disappearance of a large filament on the solar disk, and an increase of > 10 MeV protons two days earlier than time of SSC (Huttumen et al, 2002). A magnetogram at Ettaiyapuram, an equatorial electrojet station in India for the storm has been reproduced in Fig. 4. The trace shows, SSC impulses in H is 69 nT and that of D is 15 nT. The H field had reached the minimum at 0015 LT on 7 April 2000, ΔH with respect to pre-disturbed value was –317 nT. The storm-time depression in H field corrected for quiet day values was –30 nT for H and –96 nT for D.

The tracings of H and D magnetograms from 1 to 11 April 2000 at number of equatorial electrojet stations operated by Kyushu University are shown in Fig. 5. First, a large decrease of H with a minimum around 0000UT on 7 April 2000 is clearly seen at all of the stations. At Ancon where ψ-D is small, the decrease of H was associated with an uncertain and very small decrease of D. At Eusebio with a large ψ-D, +15.7^0 the decrease of H was associated with a large decrease of D. At Garou with a negative large ψ-D (-9.9^0) the decrease of H was associated with a large increase of D. At station in East Indies Davao (DAV), Cebu (CEB) and Yap (YAP) the normal midday peak of H field due to the equatorial electrojet were obliterated by the equatorial ring current effects. At all these stations having small positive ψ-D, the decrease of H is associated with the slight decrease of D field. Thus, the storm-time variations in declination are consistent with the ψ-D at the station as suggested by Rastogi et al. (2001).

CONCLUSIONS

The study of the traces of H and D fields at the network of geomagnetic stations around the world established by the Kyushu University, Japan has fully confirmed the earlier suggestions by Rastogi et al (2001) that the equatorial disturbance ring current follows the dipole coordinates of the earth and follows the relation $\Delta Y/\Delta H = \sin(\Psi\text{-}D)$ where Ψ is the dipole declination at magnetospheric level and D is the ground declination at the station concerned. The above relation has been verified in American sector, African sector and Asian sector.

ACKNOWLEDGEMENTS

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