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Response of equatorial electrojet during the super geomagnetic storm of April 2000

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A major geomagnetic storm associated with coronal mass ejection (CME) occurred with sudden commencement at 1636 hrs UT on 6 April 2000 and a minimum Sym/H index of -300 nT at 0000 hrs UT on 7 April 2000. The event is unique with IMF Bz remaining southward from around 1630 hrs UT till almost midnight. The event is studied from data at a chain of ground magnetometers in the Indian and Pacific longitude sectors and other low latitude stations. The amplitude of SC (H) at low latitude stations was highest at Huancayo (around local mid-day) with a value of about 150 nT and about 45 nT at Tirunelveli in the Indian sector (nighttime). The amplitude of SC in H in the night side Indian sector showed an increase with latitude with a value of about 45 nT near dip equator and increased to about 85 nT near Sq focus. Counter electrojet was seen from 0400 to 1100 hrs UT (maximum value of -70 nT) in the Indian sector and the ionograms at Thumba showed disappearance of Es-q at 1130 hrs LT (0630 hrs UT) and its reappearance at 1630 hrs LT (1130 hrs UT). The long duration counter electrojet in the Indian sector is likely due to disturbance dynamo fields. Strong counter electrojet event from 0000 to 0300 hrs UT (maximum value of about -300 nT) in the far-east sector is probably due to prompt penetration electric field (over shielding) associated with the sudden northward turning of IMF Bz around midnight.

Keywords: Equatorial electrojet, Space weather, Geomagnetic storm, Equatorial ionosphere

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1 Introduction

On 4 April 2000, a coronal mass ejection (CME) took place close to the western limb of the Sun at 1632 hrs UT associated with a C 9.7 solar flare in active region AR8933 (N18W58) at 1524 hrs UT. A strong southward interplanetary magnetic field (IMF Bz) in the sheath region caused a magnetic storm that was the second largest in 2000 with hourly Dst index value of -288 nT (Sym/H index of -300 nT) around 0000 hrs UT on 7 April. The unique feature of the storm was an intense and long sustained southward IMF Bz and a very large solar wind magnetic pressure. IMF Bz turned northward after midnight. Features of the ionosphere and magnetosphere associated with the storm of April 2000 have been reported[1-7]. Huttunen *et al.*[1] described the response to the April 2000 geomagnetic storm from more than 80 magnetometer stations at latitudes higher than 40°N. Afraimovich *et al.*[2] described the traveling ionospheric disturbances (TIDs) using total electron content data from GPS receivers in Russia and central Asia. Su *et al.*[3] described the equatorial spread-F (ESF) plasma depletion structures in Chinese midnight period. Lee *et al.*[4] described the observations of TIDs at middle and low latitude stations Wuhan and Chungli. Liu *et al.*[5] reported the ionospheric response to the storm of April 2000 using the digisonde data at Chungli, Wuhan and Kokubunji. Jadav *et al.*[6] described the features of interplanetary scintillations recorded at Rajkot. Pimenta *et al.*[7] described the observations of plasma bubbles associated with large scale plasma density depletions in the nighttime low-latitude F-region in the Brazilian sector through the all sky OI 630 nm images. The magnetic storm of April 2000 resulted in both the prompt penetration electric field and the disturbance dynamo effects and also TIDs.

Inspite of numerous studies of the April 2000 geomagnetic storm, no study has been made on the magnitude of sudden commencement (SC) and ionospheric currents at low latitude stations. The present paper describes the results of the analyses of geomagnetic data for the April 2000 storm at the chain of stations in India and far-east.

2 Equatorial electrojet and related topics

The abnormally large solar daily range of the horizontal component of the geomagnetic field H, within ±3° dip latitude, known as equatorial electrojet (EEJ)[8], is due to the enhanced currents caused by an abnormally large electrical conductivity[9-10]. The solar cycle variations in electrojet strength are primarily caused by the changes in electron density while the day-to-day variability is primarily caused by the electric field[11]. Ionospheric drift measurements from spaced receiver technique at Thumba showed a high correlation between drift velocity and electrojet strength as determined from the difference between ΔH at Trivandrum, close to the dip equator and at Alibag, outside the equatorial region[12]. Anderson *et al.*[13] showed quantitative relationship based on the Jicamarca incoherent scatter radar drift observations and magnetometer data at Canete and Piura in Peru. Thus, in the absence of electric field measurements, one can use electrojet strength as an index of the electric field in ionosphere (E-region).

Rastogi & Patel[14] showed that the sudden and large northward turning of interplanetary magnetic field (IMF) was associated with the sudden reversal of ionospheric plasma drifts over Jicamarca. It was suggested that the solar wind moving with a velocity V across the IMF Bz is equivalent to an interplanetary electric field E = - V×Bz. This field is transferred to the polar region and then to the equatorial latitudes without any delay. Thus, magnetospheric electric fields penetrate to low latitudes and modify the ionospheric electric fields of tidal winds origin. There are broadly two types of disturbance electric fields: (i) a direct penetration of magnetospheric electric field, associated with storm sudden commencements and substorm development/decay[14-16] and (ii) a disturbance dynamo electric field produced by changes in the thermospheric circulation due to energy deposition at high latitudes that follow with time delays of few hours with respect to the prompt penetration of electric field[17-19]. Besides the effects due to the disturbance electric fields, equatorial ionosphere also undergoes changes due to the modifications in the thermospheric dynamics and composition.

The solar wind interaction with magnetosphere is quite a complex process and largely depends on the IMF conditions. Prompt penetration electric field is generally composed of convection electric field and over shielding electric field. The shielding electric fields are built up equatorward of the auroral latitudes and are often reversed when the convection field is decreased suddenly because of the northward turning of the IMF Bz and known as over shielding electric field. For IMF Bz turning northward (over shielding effect), the interplanetary electric field is directed westward during day and eastward during night while for southward turning of IMF Bz (under shielding effect), the resulting field is directed eastward during day and westward during night. Thus, the prompt penetration electric field enhances the daytime eastward dynamo field.

The geomagnetic storm of 6 April 2000 is unique with IMF Bz turning southward around 1630 hrs UT and remained southward till almost midnight. The event occurred in the dayside in American longitudes (1100 hrs LT) and night side in the Indian longitudes (2200 hrs LT). The event is studied from data at a chain of ground magnetometers in the Indian and Pacific longitude sectors, low latitude magnetometer stations at different longitude sectors, solar wind and IMF data and ionosonde data from Thumba.

3 Results

3.1 Solar wind parameters and IMF

The IMF Bz and solar wind parameters (density, velocity, flow pressure and electric field), AE index and Sym/H index from 1200 hrs UT on 6 April 2000 to 1200 hrs UT on 7 April 2000 are shown in Fig. 1. Also plotted in the figure are the geomagnetic H field at the magnetic equatorial stations, Huancayo (75°W), Tirunelveli (77°E) and Bangui (18.6°E). The impact of the plasma blob from CME on the earth's magnetosphere was at 1630 hrs UT. The flow speed was around 350 kms^{-1} before the impact and it rapidly increased to 500-600 kms^{-1} at 1630 hrs UT and continued at that level till 1200 hrs UT on 7 April. The density was 5-6 cm^{-3} and increased at 1630 hrs UT to close to 20 cm^{-3}. It later increased to 35 cm^{-3} with peaks at 2300 hrs UT and 0300 hrs UT before coming to normal value at 0900 hrs UT on 7 April. As there was not much variation in the flow speed from 1630 hrs UT onwards, the flow pressure variation was very similar to that of density. Flow pressure increased to 10 hPa at 1630 hrs UT and peaked later to about 20 hPa. IMF Bz was slightly negative before the impact, decreasing after the shock to values below -10 nT. It remained southward till around midnight with a value of -20 nT except for a brief period when it turned positive around 2230 hrs UT. The computed electric field was close to zero initially and exceeded 10 mV m^{-1} between 1630 and

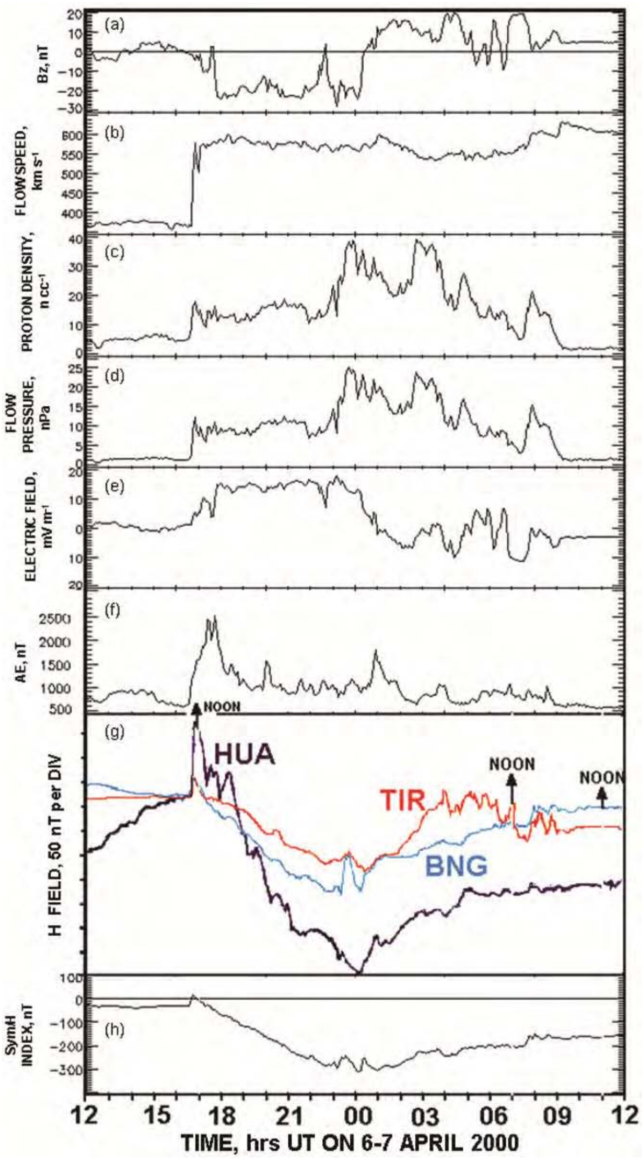

Fig. 1 — Variations of: (a) interplanetary magnetic field (IMF Bz); (b) solar wind flow velocity (V); (c) proton density; (d) flow pressure; (e) estimated interplanetary electric field (-V×Bz); (f) auroral AE index; (g) geomagnetic H field at Huancayo (HUA), Tirunelveli (TIR) and Bangui (BNG); and (h) Sym/H index from 1200 hrs UT on 6 April 2000 to 1200 hrs UT on 7 April 2000

0000 hrs UT. After midnight, it turned negative and then fluctuated between negative (maximum value of -10 mV m^{-1}) and positive (6 mV m^{-1}) because of the changes in the direction of IMF Bz. Auroral electrojet index (AE) rose from few hundred nT to 2500 nT at 1730 hrs UT following the changes and gradually returning to values of about 1000 nT around 1900 hrs UT. It showed another peak of 1800 nT associated with the northward turning of IMF Bz around midnight.

Table 1 — Geographic coordinates and dip angle of stations

Station	Code	Latitude, °N	Longitude, °E	Dip, °N
Huancayo	HUA	-12.1	-75.3	0.9
Ascension Island	ASC	-8.0	-65.6	-11.6
Bangui	BNG	4.4	18.6	-16.0
Hermanus	HER	-34.4	19.2	-66.0
Papeete	PPT	42.5	24.2	-32.0
Tirunelveli	TIR	8.7	77.7	1.9
Etaiyapuram	ETT	9.2	78.0	2.5
Pondicherri	PND	11.9	79.9	9.2
Visakapatanam	VSK	17.7	83.3	22.3
Nagpur	NGP	21.1	79.1	20.9
Alibag	ABG	18.6	72.9	25.3
Ujjain	UJJ	23.2	75.8	33.9
Gulmarg	GUL	34.1	74.6	51.9
Kashi	KSH	39.5	76.0	58.7
Alma Ata	AAA	43.3	76.9	62.5
Pohnpei	PON	7.0	158.3	1.2
Yap	YAP	9.5	138.0	3.6
Davao	DAV	7.1	125.6	-1.2
Cebu	CEB	10.3	123.9	5.8
Muntilupa	MUT	14.4	121.0	15.3
Phu Thuy	PHU	21.0	106.0	29.3
Lunping	LNP	25.0	121.2	21.0
Kanoya	KNY	31.4	130.9	45.0
M'Bour	MBO	14.4	343.0	10.0
Thumba	TRD	8.5	76.5	1.6

The geomagnetic H field showed large sudden commencement at Huancayo with amplitude of more than 150 nT. It must be noted that the time of SC is local noon at Huancayo when electric conductivity is maximum. At Tirunelveli, the amplitude of SC was 45 nT (2200 hrs LT). The decrease of H following the SC was about 350 nT at 0000 hrs UT. One can notice fluctuations in H at Tirunelveli between 0400 and 0900 hrs UT (around local noon) associated with the fluctuations in the electric field. The Sym/H index showed decrease of about 300 nT around 0000 hrs UT.

3.2 Geomagnetic variations

The geomagnetic H, Z and Y components at the chain of observatories in India have been studied for the event. The list of stations with geographic coordinates and dip latitude are listed in Table 1. The stations cover the region from dip equator to Sq focus. The stations are Tirunelveli (TIR), Pondicherry (PND), Visakapatnam (VSK), Nagpur (NGP), Alibag (AGB), Ujjain (UJJ) and Gulmarg (GUL). The variations of the H field at all the stations are shown in Fig. 2(a) from 1600 hrs UT (2100 hrs LT) on 6 April 2000 to 1000 hrs UT (1500 hrs LT) on 7 April 2000. The SC amplitude was 85 nT at GUL near Sq focus and decreased gradually at stations closer to dip equator (45 nT at TIR). Following the SC, there was rapid decrease in H field of about 220 nT with minimum around midnight. There was small increase at about 2015 hrs UT with change of about 10-15 nT. Another increase was seen at about 2300 hrs UT. The amplitude of this increase was about 50 nT at TIR and increasesd with latitude to about 100 NT at GUL. Minor increases were also seen around 1730 hrs UT and 1815 hrs UT that also became more prominent with increasing latitude. The H values recover to pre SC value at about 0400 hrs UT. There were fluctuations from 0400 to 1000 hrs UT due to local day time. The fluctuations in this time period were larger at TIR near dip equator and decreased with latitude.

The variations in Z field at all the stations are shown in Fig. 2(b). The amplitude of SC in Z was largest at TIR (80 nT) and decreased with increasing latitude at PND and VSK. It was negative at NGP, ABG, UJJ and GUL. Following the SC at 1636 hrs UT, the Z values showed a large decrease at TIR and comparatively much smaller decreases at PND and VSK. Opposite was the case at NGP, ABG, UJJ and GUL where small increase was seen after the SC. The increase in Z at 2000 hrs UT at TIR (more than 50 nT) was also seen at PND and VSK with decreasing amplitudes. At NGP, ABG, UJJ and GUL, there was decrease. The fluctuations seem to be in opposite directions at the two groups of stations (large peak at 2230 hrs UT and the big dip just after 0000 hrs UT at TIR). Similar to large fluctuations in H at TIR between 0400 and 1000 hrs UT, one notices large fluctuations in Z also. The amplitude of fluctuations decreased with latitude.

The SC amplitude in Y component was negative and smaller, less than 10 nT at PND to 30 nT at ABG. Following the decrease after SC, there was an increase with the broad maximum coinciding with the dip around 0000 hrs UT in H and Z variations. The fluctuations were also seen from 0400 to 1000 hrs UT as in case of H and Z components. The variations in Y before 0000 hrs UT were smaller at TIR and PND in the electrojet region as compared to stations away from electrojet.

An examination was made to study the variation with inclination of the SC amplitudes in H, Z and Y

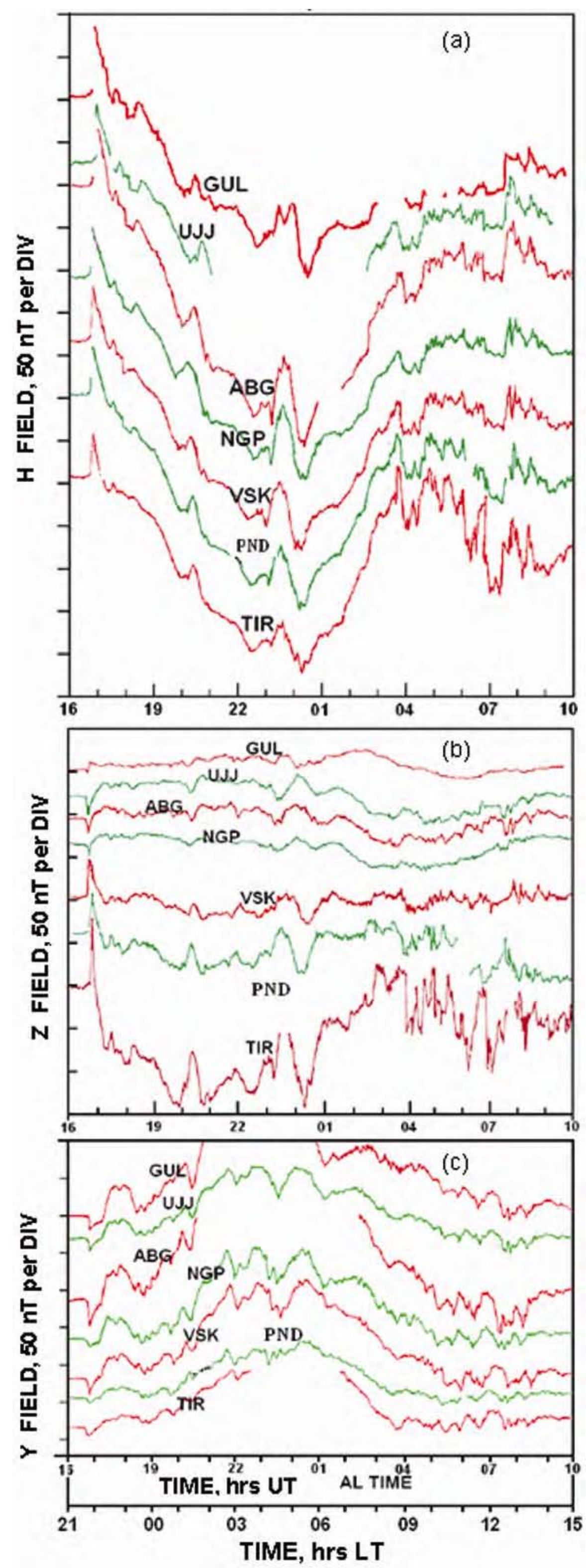

Fig. 2 — Variations of geomagnetic H, Z and Y components at a chain of stations in the Indian region from 1600 to 1000 hrs UT on 6-7 April 2000

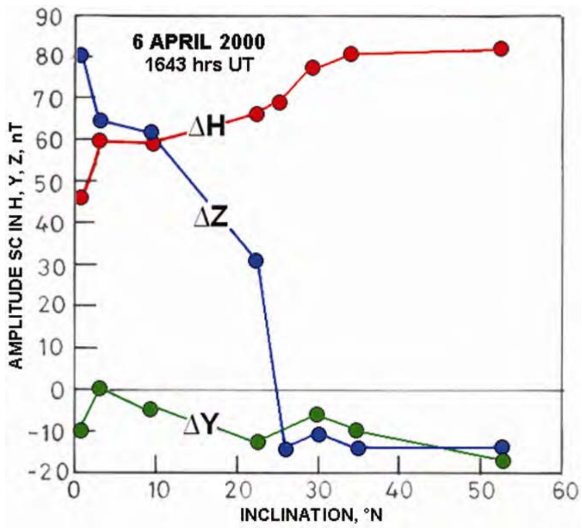

Fig. 3 — Amplitudes of SC in H, Z and Y components of the geomagnetic field at the chain of Indian stations plotted as a function of inclination on 6 April 2000

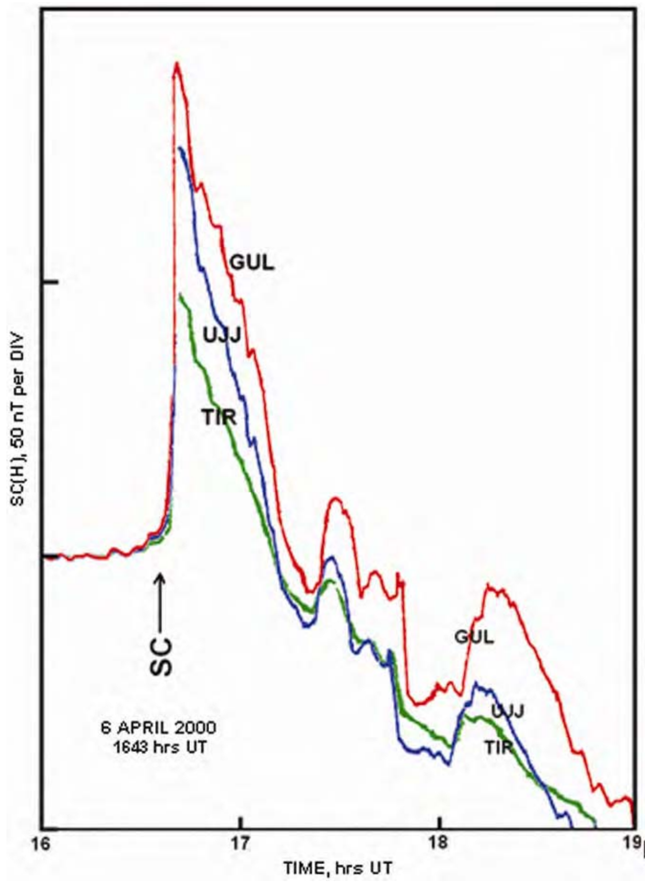

Fig. 4 — Variations of geomagnetic H field at Gulmarg (GUL), Ujjain (UJJ) and Tirunelveli (TIR) from 1600 to 1900 hrs UT on 6 April 2000 showing the SC

components (Fig. 3). The amplitude of the SC in H increased with latitude. It was 45 nT at dip equator and increased to about 85 nT at an inclination of 53°N. The amplitude of SC in Z decreased with inclination. It was 80 nT at dip equator and decreased to less than 10 nT at inclinations higher than 25°N. It decreased sharply from inclination angles of 22° to 25°N. The variation with inclination of the SC amplitude in Y was not consistent. It was -10 nT at dip equator, decreased to almost zero at PND, and then increased to about -10 nT at an inclination of 22°. It showed another decrease around 30° before increasing again near Sq focus.

The variations in the H component between 1600 and 1900 hrs UT for the three stations TIR (electrojet region), UJJ (in between) and GUL (near Sq focus) are shown in Fig. 4. The amplitudes of the SC in H were 45 nT, 70 nT and 85 nT at TIR, UJJ and GUL, respectively. The variations were almost similar at the three locations. During the decreasing phase, secondary peaks were seen around 1730 and 1815 hrs UT. The peaks at TIR and UJJ were at almost same time but the peaks at GUL were delayed by about 3 minutes. The amplitude of the secondary peaks also showed an increase with latitude with larger fluctuations of ΔH at Gulmarg and minimum at TIR.

The storm time variations of ΔH for stations in the Indian longitude sector are shown in Fig. 5 based on hourly values plotted from 1200 to 1200 hrs UT for 6-7 April 2000. The stations are Tirunelveli (TIR), Etiapuram (ETT), Pondicherri (PND), Hyderabad (HYB), Nagpur (NGP), Alibag (ABG), Ujjain (UJJ), Sabawala (SAB) all Indian stations along with Kashi (KSH) and Alma Ata (AAA). Hourly Dst index is also plotted in the figure. The difference of ΔH at ETT and ΔH at ABG is also plotted that represents the equatorial electrojet. Following the SC, the Dst index reached -295 nT around 0000 hrs UT. The ΔH values show maximum negative value of -350 nT at TIR. This decreases with latitude as seen from the plots for different stations (maximum negative values also marked in figure). The maximum negative values lie between -350 nT at TIR and -250 nT at AAA.

The electrojet strength, as inferred from the differences of ΔH at ETT and ΔH at ABG, shows very weak electrojet from 0100 to 0400 hrs UT (0600 to 0900 hrs LT). There is counter electrojet from 0400 to 1100 hrs UT (0900 to 1600 hrs LT). There is hardly any variation between 1200 to 0100 hrs UT (1700 to 0600 hrs LT) as this is basically night side. Thus, the event led to very large duration of counter electrojet lasting a few hours. The maximum counter electrojet

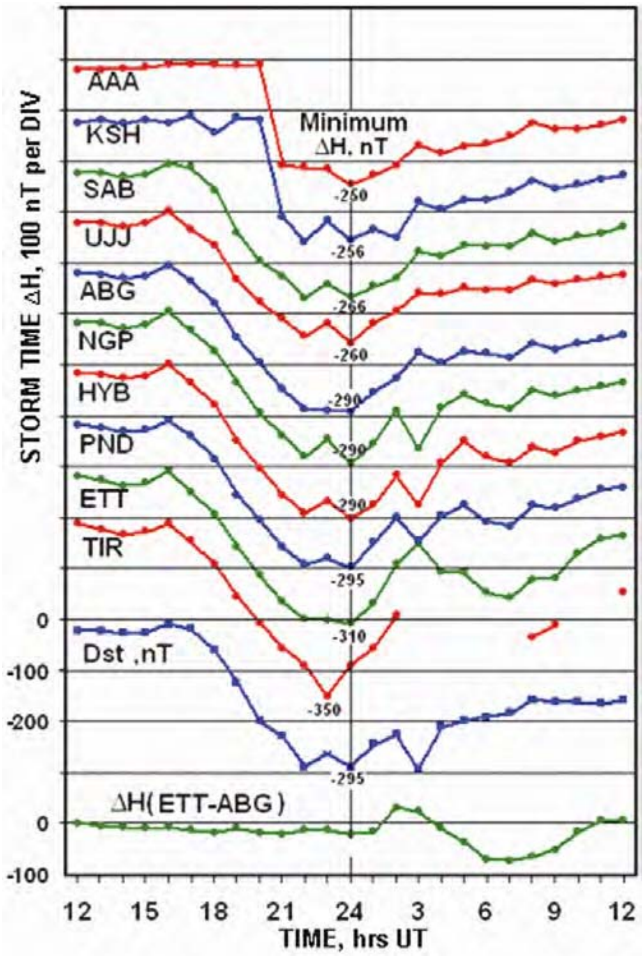

Fig. 5 — Variations of storm time ΔH [after subtracting Sq(H) part] at a chain of stations in the Indo-Russian longitude sector from 1200 hrs UT on 6 April 2000 to 1200 hrs UT on7 April 2000; difference in ΔH at ETT (near dip equator) and ABG (off dip equator) also plotted

strength was about -70 nT. It is to be noted that the counter electrojet occurred during the recovery phase of the geomagnetic storm. This is probably caused by the disturbance dynamo field associated with the geomagnetic storm.

The ΔH variations for a chain of stations in the Pacific longitude sector are shown in Fig. 6. The stations are PON, YAP, DAV, CEB, MUT, PHU, LNP and KNY. The Dst index and the electrojet strength (ΔH at PON, -ΔH at MUT) are also plotted in the figure. The maximum negative values for all stations are also marked in the figure. The values are much higher than for the Indian longitude stations. These range from -500 nT at PON to -260 nT at KNY. Thus, while the stations near the Sq focus show almost similar values, the stations in the low latitudes show larger negative values in the far-east longitude sector. The electrojet strength also shows counter electrojet during 1500-1800 and 1900-2300 hrs UT and a very strong counter electrojet event during 0000-0300 hrs UT (more than -300 nT). The counter electrojet was unusually large and probably associated with the over shielding effect with sudden northward turning of IMF Bz around midnight. It must be noted that the pair of stations PON and MUT are not in same longitude region and the difference of 37^{o} in longitude is not ideal to estimate the electrojet strength but even if correction of local time is considered, the event is very large.

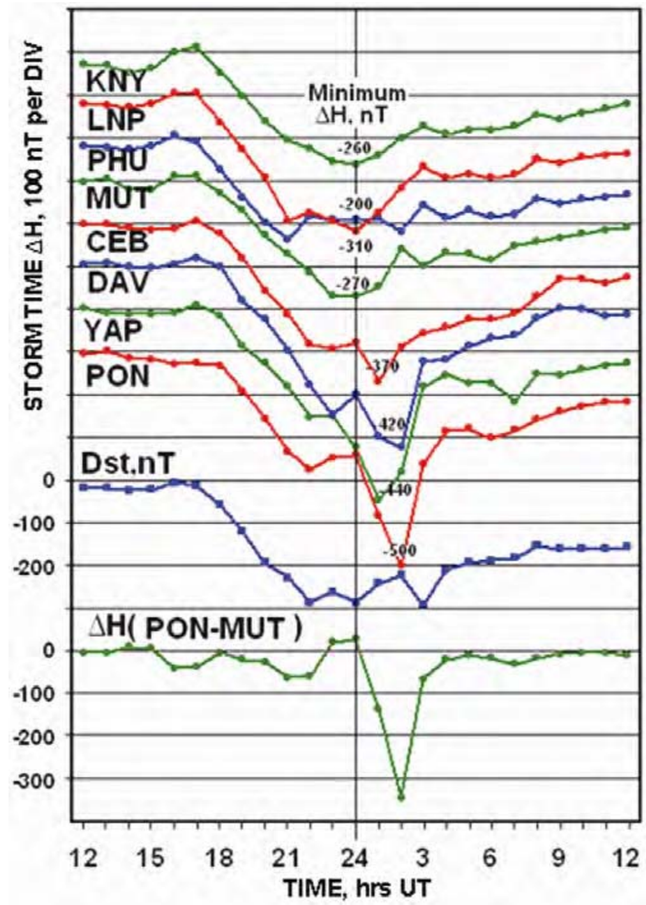

Fig. 6 — Variations of storm time ΔH [after subtracting Sq(H) part] at a chain of stations in the Far-East longitude sector from 1200 hrs UT on 6 April 2000 to 1200 hrs UT on 7 April 2000; difference in ΔH at PON (near dip equator) and MUT (off dip equator) also plotted

The storm time ΔH values (maximum negative values) for all the stations in the two longitude sectors are shown in Fig. 7 plotted as a function of inclination angle. In the Indian longitude sector, the values range from -350 nT at TIR (dip equator) to -250 nT at AAA (Sq focus). In the Pacific longitude sector, the

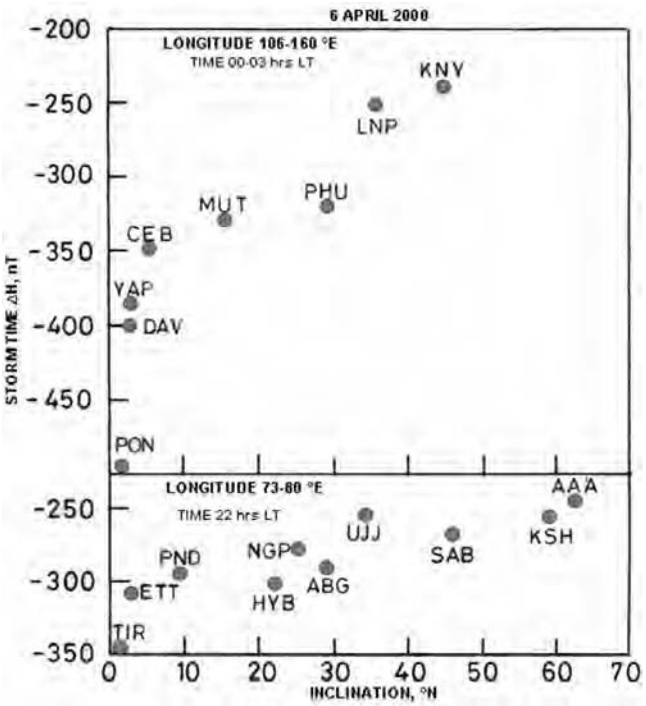

Fig. 7 — Maximum storm time decrease in H plotted as a function of inclination angle for the Indo-Russian (73°- 80°E) and far-east (106°- 160°E) longitude sectors

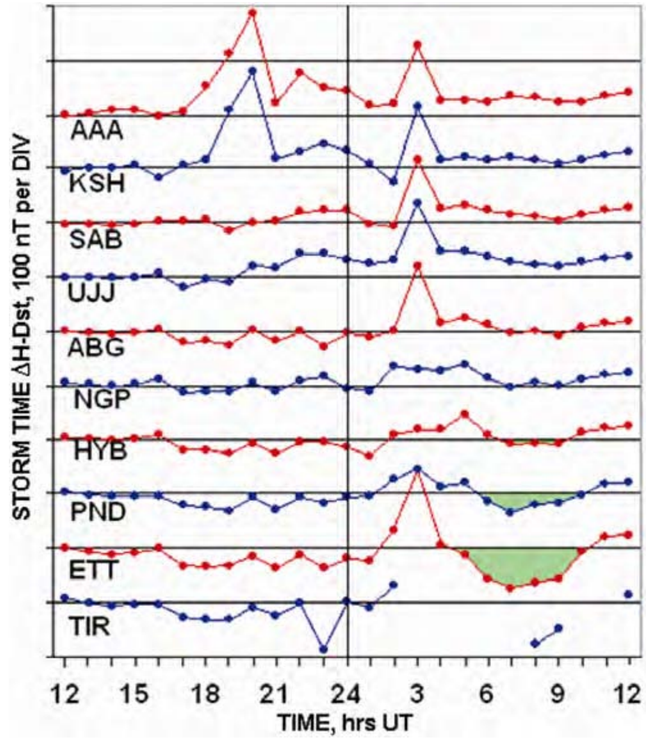

Fig. 8 — Variations of the storm time ΔH after subtracting Dst at a chain of stations in the Indian longitude sector from 1200 hrs UT on 6 April 2000 to 1200 hrs UT on 7 April 2000

variation is much steeper. Even for stations close to dip equator, the values decrease sharply from -500 nT at PON to -350 nT at CEB. Thus, high values are seen at stations close to dip equator. It is to be noted that the latitudinal variation is larger in the midnight longitude sector than in the dusk sector.

The variations of the storm time ΔH values after subtracting the Dst values for 6-7 April 2000 (1200 to 1200 hrs UT) at the stations in the Indian longitude sector are shown in Fig. 8. There was no data during 0300 – 0800 hrs UT on 7 April for TIR. Almost all stations show sudden increase of 100 nT or more from 0200 to 0300 hrs UT. The increase at PND is only about 50 nT while there is no increase at NGP and HYB. The two stations AAA and KSH show an increase of almost 200 nT from 1800 to 2000 hrs UT on 6 April 2000. The counter electrrojet is seen on 7 April 2000 from 0500 to 1000 hrs UT at ETT with maximum value of about -70 nT. Though, there is missing data for TIR but counter electrojet is clearly seen from the values at 0800 hrs UT (about -70 nT) and 0900 hrs UT (about -50 nT). At PND, counter electrojet is seen from 0600 to 1000 hrs UT with maximum value of about -35 nT. There is an indication of very weak counter electriojet from 0700 to 0900 hrs UT at HYB with maximum value of about -10 nT. The counter electrojet peak is seen around 0700 hrs UT, which is midday.

The plots of storm time ΔH values after subtracting Dst at stations in the far-east longitude sector are shown in Fig. 9. The increase from 0200 to 0300 hrs UT with maximum at 0300 hrs UT of about 100 nT is again noticed at KNY, LNP, PHU and MUT. However, this is masked by the counter electrojet at CEB, DAV, YAP and PON. The counter electrojet appeared from 0000 hrs UT to little before 0300 hrs UT with maximum magnitude of about -125 nT at CEB, -200 nT at DAV and YAP and about -280 nT at PON. The maximum of counter electrojet is centered between 0100 and 0200 hrs UT, which is close to the local midday.

The effect of the large changes in the ionospheric electric field due to the magnetic storm of 6-7 April 2000 that resulted in strong counter electrojet is shown in Fig. 10. Selected ionograms at Thumba are reproduced. At 1115 hrs LT, the ionogram is normal with clear equatorial sporadic-E (Es-q). Ionograms at 1130, 1245, 1500 and 1545 hrs LT do not show any trace of Es-q. This confirms the reversal of electric field from eastward to westward. The ionogram at 1630 hrs LT shows clear Es-q. Thus, the electric field

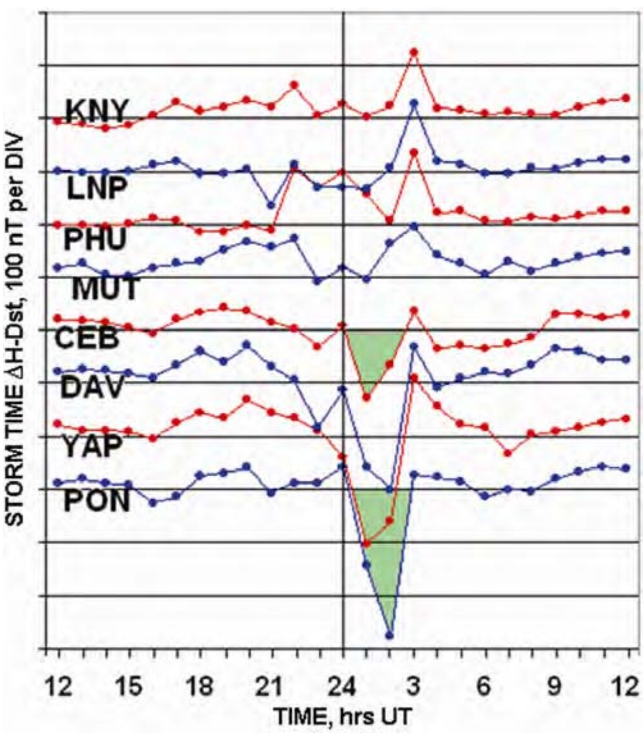

Fig. 9 — Variations of the storm time ΔH after subtracting Dst at a chain of stations in the far-east longitude sector from 1200 hrs UT on 6 April 2000 to 1200 hrs UT on7 April 2000

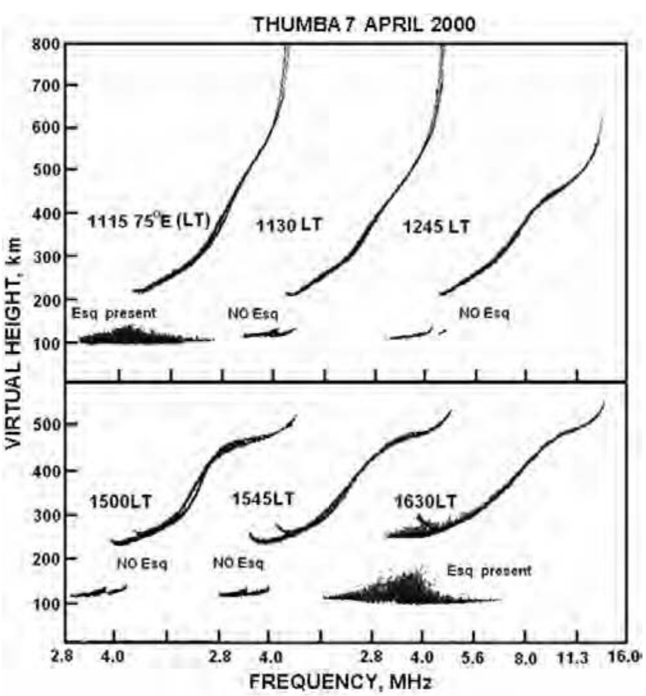

Fig. 10 — Ionograms at Thumba for selected time (from 1115 to 1630 hrs LT) showing disappearance of Es-q at 1130 hrs LT and reappearance at 1630 hrs LT

again turned eastward. The disappearance of Es-q for almost 4 hours that too around midday is rare.

The magnetograms of X and Y components on 6 and 7 April 2000 at a few selected stations Huancayo, Ascension Island, Bangui, Phu Thuy and Papeete are reproduced in Fig. 11. For Hermanus and Alibag, H and D magnetograms are reproduced. The base values of the X and Y components (H and D) and the scale for variation per division are also mentioned in the figure for each of the stations. The variations of the X (H) component at all stations are almost similar following the SC around 1630 hrs UT on 6 April with decrease of up to few hundred nT around 0000 hrs UT. The magnitude of SC is largest at Huancayo. The variation of the Y (D) component is different location wise. At Huancayo, following the positive SC (~40 nT), the value of Y decreasesd with minimum around midnight (UT) similar to the variation of X. At Ascension Island, the SC in Y is negative (30 nT) and following it, Y increases. The variation of Y at Bangui is similar to at Ascension Island. At Hermanus, the SC is positive in H and absent in D. Both H and D decrease following the SC. At Alibag, following the SC (positive) H decreases but the SC in D is negative and value of D increases after the SC. At Phu Thuy, the SC is positive in both X and Y but while there is decrease in X, Y increases following the SC. At Papeete, the SC is positive in both X and Y and both show decrease later.

Direction of the SC (H) vector is computed for the low latitude stations covering the entire longitudes and shown in Fig. 12. In the African sector, the SC(H) vector is aligned west of north at SPT, GUI, MBO, TAM and BNG situated in the northern hemisphere; and along east of north at HER, HBK and TAN in the southern hemisphere. In the Indian region, the vector is aligned west of north at the Indian stations but east of north at AMS in southern hemisphere. In the far-east region, the vector is aligned east of north at all the stations both in northern and southern hemisphere. In the American sector, the vector is aligned along west at FRN and TUC, and west of north at DLR, BSL and HUA. The magnitude of the vector varies from station to station but it is very high for Huancayo, 2-3 times higher than other stations.

4 Discussions

Analyzing the characteristics of SC in H, Y and Z at Indian observatories Trivandrum, Kodaikanal, Annamalainager and Alibag for the period 1958-1992,

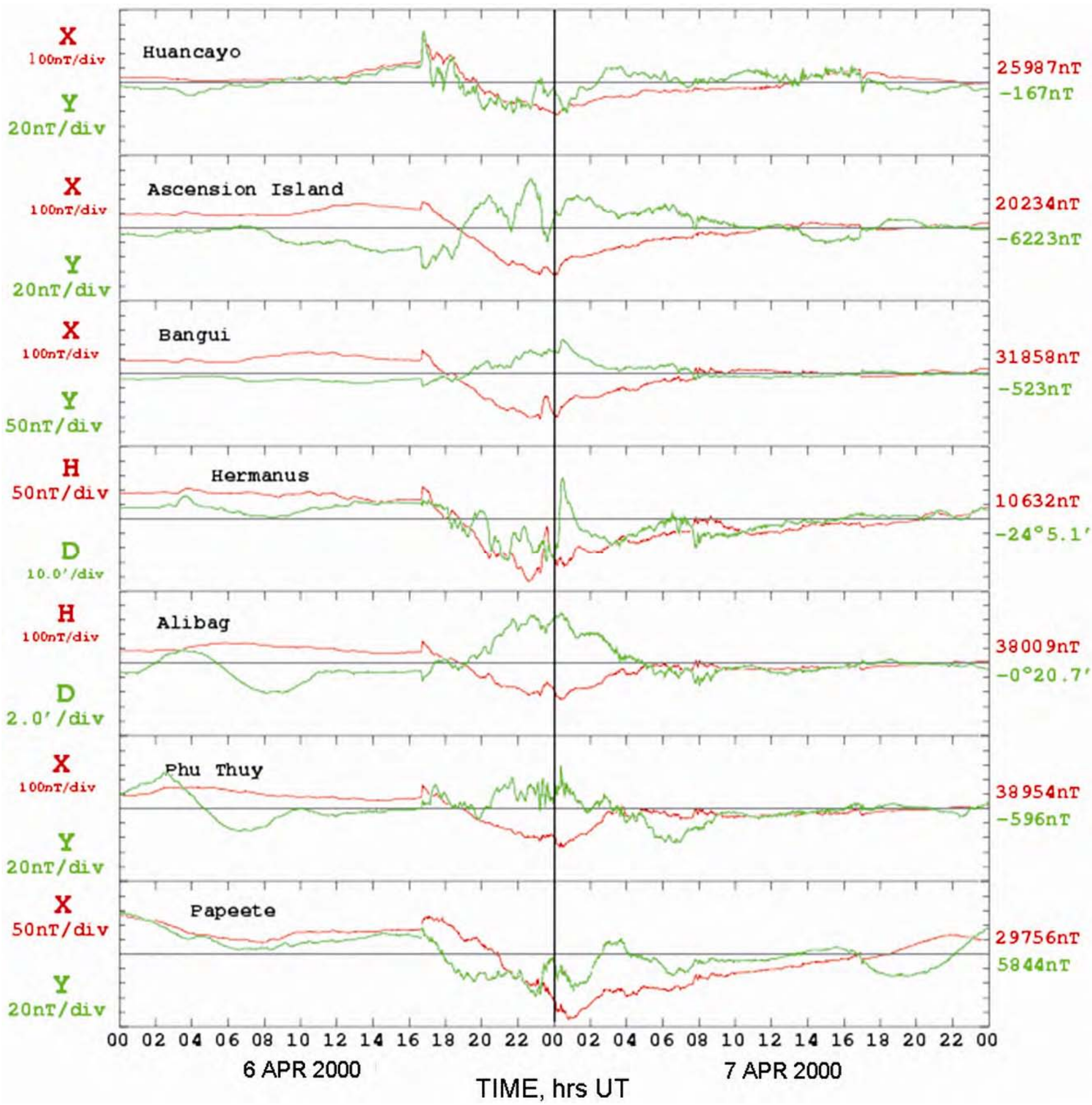

Fig. 11 — Magnetograms showing geomagnetic X and Y (H and D at Hermanus and Alibag) components for 6-7 April 2000 at few stations around the globe showing SC and storm time variations

Rastogi[20] had shown that the amplitude of SC in H during the daytime increased with decreasing dip angle while during the nighttime SC in H did not show any significant latitudinal variation. Later Rastogi *et al.*[21] analyzed data at a chain of stations in the Indian longitude sector for 23 day time and 16 night time SC events. Daytime events showed maximum amplitude of SC (H) at dip equator, however, for the night time events the amplitude decreased near the magnetic equator. The ratio of mean amplitude in day time to night time amplitude of SC (H) was 2.9, 2.3, 2.2 and 1.7 at Trivandrum, Etiapuram, Kodaikanal and Anamalainager, respectively. For stations Hyderabad to Gulmarg, the ratio was close to 1.0. The present data also show rather unexpected feature of decreasing amplitude of SC (H) with decreasing inclination. Sudden commencement is primarily due to the compression of the

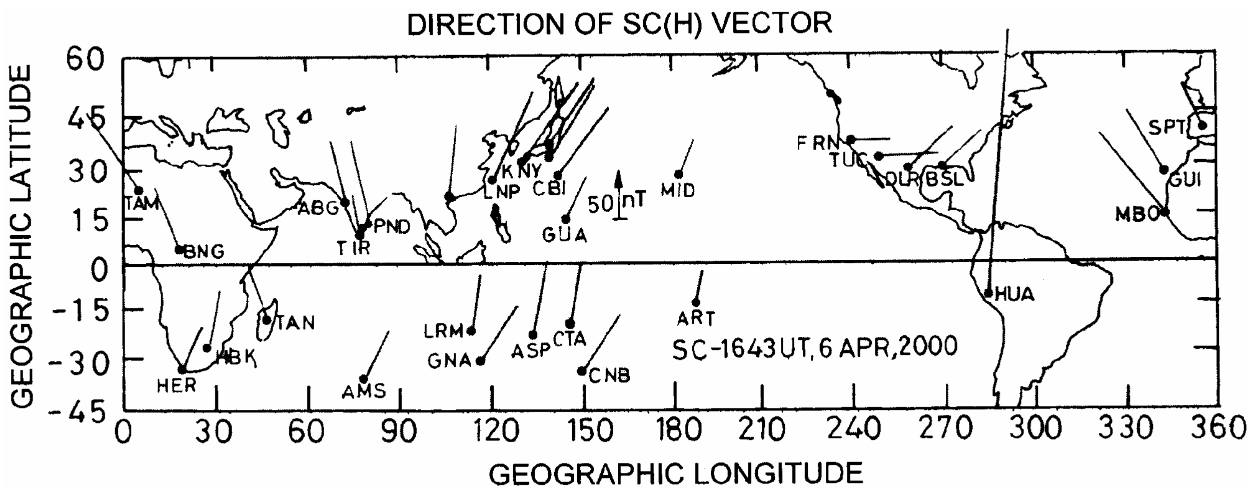

Fig. 12 — SC(H) vector plotted on a scale of latitude *vs* longitude showing direction and magnitude of SC(H)

magnetosphere due to the sudden increase in solar wind dynamic pressure. The disturbance field of SC is considered to be due to two components: the DL component originating as an abrupt increase of magnetopause current and the other DP due to a polar electric field transmitted along the lines of force from magnetosphere.[22] High latitude dusk to dawn electric field can penetrate to low latitudes as a zeroth order transverse magnetic wave guide mode. However, in addition to the magnetopause currents, there are secondary effects like the field-aligned currents, ionopspheric currents and the tail currents that contribute to the disturbance field of SC. The polarity of the IMF Bz also determines the response to the solar wind dynamic pressure. Luhr *et al.*[23] studied a large number of night time SC observed from CHAMP satellite and ground based magnetometers and confirmed the assumption that night time SC signatures are not or minimally affected by ionospheric currents for magnetic latitudes below ±40°. They observed increase of SC amplitude with latitude pole ward of ±40° magnetic latitude and attributed this to field-aligned currents. Russel *et al.*[24,25] studied the response of low-latitude H component during the passage of interplanetary shocks both during the northward and southward IMF Bz conditions. For the northward IMF, magnetopause currents govern principally the amplitude of SC during dayside. Tail currents, which act in the opposite sense to magnetopause currents are also enhanced and have greater effect in the night than in daytime hours. In case of southward IMF, daytime response to solar wind pressure increase is over 25% smaller probably because of current system associated with dayside reconnection, however, at night, the mid and low-latitude response is much greater and attributed to the triggering of substorms in magnetotail[25]. Huttunen *et al.*[1] reported eight auroral electrojet enhancements during the main phase of the April 2000 magnetic storm. Out of this, four activations were attributed to substorm activity (1805, 2013, 2315 and 0030 hrs UT). The traces of the H magnetograms at the chain of stations in India (Fig. 2) show enhancements at these times and the enhancement amplitude increases with latitude.

The latitudinal variation of SC (Z) in the Indian longitude sector with maximum at dip equator followed by a decrease with increasing latitude and negative values beyond 20° inclination is similar to the earlier findings of Rastogi *et al.*[21]. The high values of SC (Z) at equatorial latitudes in the Indian sector both during daytime and night time were attributed to induction effects due to complex distribution of electric conductivity at the southern tip of India.

Other important observation is the counter electrojet events seen at both Indian and far-east longitude sector. The counter electrojet event in the Indian sector is a long duration event of more than four hours with maximum strength of -70 nT. This event occurred during 0500-1000 hrs UT and is likely caused by disturbance dynamo effects. More importantly, the counter electrojet in far-east sector, just after midnight and lasting for almost two hours, was very strong event with maximum strength of about -300 nT. This event seems to be due to the sudden northward turning of IMF-Bz around midnight and therefore, due to the prompt penetration electric field (over shielding).

5 Summary

A major geomagnetic storm associated with coronal mass ejection (CME) occurred with sudden commencement at 1636 hrs UT on 6 April 2000 and minimum of hourly Dst of -288 nT at 0000 hrs UT on 7 April 2000. The event is unique with IMF Bz turning southward around 1630 hrs UT and remained southward till almost midnight.

The amplitude of the SC (H) was largest (more than 150 nT) at Huancayo as the event was around midday. In the Indian sector (night time), the amplitude was around 45 nT near dip equator and increased to about 80 nT near Sq focus. As the ionospheric currents are negligible during night, this suggests role of additional currents in magnetosphere.

Counter electrojet was seen from 0400 to 1100 hrs UT (maximum value of -70 nT) in the Indian sector The ionograms at Thumba showed disappearance of Es-q at 1130 hrs LT (0630 hrs UT) and it reappeared at 1630 hrs LT (1130 hrs UT). This appears to be caused by disturbance dynamo. The counter electrojet in the far-east was from 0000 to 0300 hrs UT (maximum value of about -300 nT). There could be role of prompt penetration (over shielding) associated with sudden northward turning of IMF Bz around midnight.

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References

1 Huttunen K E, Keskinen H E, Pulkkinen T I, Pulkinen A, Palmorth A, Reeves E G D & Singer H S, April 2000 magnetic storm: solar wind drivers and magnetosphere response, *J Geophys Res (USA),* 107 A12 (2002) 1440, doi: 10.1029/2001/JA009154.

2 Afraimovich E L, Ashkaliev Ya F, Auskev V M, Beletsky A B, Vodyanikov V V, Leonovich L A, Lesynta O S, Lipko Yu V, Mikhalev A V & Yakovets A F, Simultaneous radar and optical observations of the mid-latitude atmospheric response to a major geomagnetic storm of 6-8 April 2000, *J Atmos Sol-Terr Phys (UK)*, 64 (2002) pp 1943-1955.

3 Su S-Y, Yeh H C, Chao C K & Heelis R A, Observations of large density dropout across the magnetic field at 600 km during the 6-7 April 2000 storm, *J Geophys Res (USA),* 107 A11 (2002) 1404, doi: 10.1029/2001JA007552.

4 Lee C- C, Liu J-Y, Reinisch B W, Lee Y-P & Liu L, The propagation of traveling ionospheric disturbances observed during the April 6-7, 2000 ionospheric storm, *Geophys Res Lett (USA)*, 29 (2002) 1068, doi: 10.1029/2001GL013516.

5 Liu L, Wan W, Lee C C, Ning B & Liu J Y, The low latitude ionospheric effects of the April 2000 magnetic storm near the longitude 120^{o}E, *Earth, Planet Space (Japan),* 56 (2004) pp 607-612.

6 Jadav R M, Iyer K N, Joshi H P & Vats H O, Coronal mass ejection of 4 April 2000 and associated space weather effects, *Planet Space Sci (UK)*, 53 (2005) pp 671-679.

7 Pimenta A A, Sahai Y, Bittencourt J A & Rich F J, Ionospheric plasma blobs observed by OI 630 nm all-sky imaging in the Brazilian tropical sector during the major geomagnetic storm of April 6-7, 2000, *Geophys Res Lett (USA)*, 34 (2009) L02820, doi: 10.1029/2006GL028529.

8 Chapman S, The equatorial electrojet as detected from the abnormal electric current distribution above Huancayo, Peru and elsewhere, *Arch Meteorol Geophys Bioclimatol (Austria)*, A4 (1951) pp 368-390.

9 Hirono M, A theory of diurnal magnetic variations in equatorial regions and conductivity of the ionospheric E region, *J Geomagn Geoelectr (Japan)*, 4 (1952) pp7-21.

10 Baker W J G & Martyn D F, Electric currents in the ionosphere 1, the conductivity, *Philos Trans R Soc Lond A (UK)*, A246 (1953) pp 281-294.

11 Rastogi R G, Geromagnetic field variations at low latitudes and ionospheric electric field, *J Atmos Terr Phys (UK)*, 55 (1993) pp 1375-1382.

12 Chandra H, Misra R K & Rastogi R G, Equatorial ionospheric drift and the electrojet, *Planet Space Sci (UK)*, 19 (1971) pp 1497-1503.

13 Anderson D, Anghel A, Yumoto K, Ishitsuka M & Kudeki E, Estimating daytime vertical E×B drift velocities in the equatorial F-region using ground-based magnetometer observations, *Geophys Res Lett* (*USA*), 29 (2002) 1596, doi: 10/1029GLO14562.

14 Rastogi, R G & Patel V L, Effect of interplanetary magnetic field on the ionosphere over the magnetic equator, *Proc Indian Acad Sci,* A 82 (1975) pp 121-141.

15 Kikuchi T, Evidence of transmission of polar electric fields to the low latitude at times of geomagnetic sudden commencements, *J Geophys Res* (*USA*), 91 (1986) pp 3101-3105.

16 Abdu M A, Batista I S, Walker G O, Sobral J H A, Trivedi N B & de Paula E R, Equatorial ionospheric electric fields during magnetospheric disturbances: local/longitudinal dependencies from recent EITS campaigns, *J Atmos Terr Phys (UK*), 57 (1995) pp1065-1083.

17 Blanc M & Richmond A D, The ionospheric disturbance dynamo, *J Grophys Res (USA)*, 85 (1980) pp 1669-1686.

18 Fejer B G & Scherliess L, Time dependent response of equatorial ionospheric electric fields to magnetospheric disturbances, *Geophys Res Lett (USA)*, 22 (1995) pp 851-854.

19 Abdu M A, Major phenomena of the equatorial ionosphere-thermosphere system under disturbed conditions, *J Atmos Sol-Terr Phys (UK)*, 59 (1997) pp 1505-1519.

20 Rastogi R G, Signatures of storm sudden commencements in geomagnetic H, Y and Z fields at Indian observatories, *Ann Geophys (France)*, 17 (1999) pp 1426-1438.

21 Rastogi R G, Pathan B M, Rao D R K, Sastry T S & Sastri J H, On latitudinal profiles of storm sudden commencements in H, Y, Z at Indian geomagnetic observatory chain, *Earth, Planets Space (Japan)*, 53 (2001) pp 121-127.

22 Araki T, Global structure of geomagnetic sudden commencements, *Planet Space Sci (UK)*, 25 (1977) pp 373-384.

23 Luhr H, Schegel K, Araki T, Rother M & Forster M, Night-time sudden commencements observed by CHAMP and ground-based magnetometers and their relationship to solar wind parameters, *Ann Geophys (France)*, 27 (2009) pp 1897-1907.

24 Russel C T, Ginskey M & Patrinec S M, Sudden impulses at low latitude stations: Steady state response for northward interplanetary magnetic field, *J Geophys Res (USA)*, 99 (1994) pp 253-261.

25 Russel C T, Ginskey M & Patrinec S M, Sudden impulses at low latitude stations: Steady state response for southward interplanetary magnetic field, *J Geophys Res (USA)*, 99 (1994) pp 13403-13408.