Disturbance daily variation of equatorial electrojet current

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Combining the long series of the simultaneous data of the horizontal component of the geomagnetic field (*H*) at the equatorial station, Trivandrum and at the low-latitude station, it has been shown for the first time that the disturbance daily variation of the equatorial electrojet current has a very clear anti-Sq shape with a minimum around noon. Disturbance atmospheric dynamo seems to be a plausible explanation, but some systematic magnetospheric processes related to local solar time may also be effective sources for the phenomenon.

WITH the availability of the data of geomagnetic *H* at only six low-latitude stations, three of these are from India. Egedal[1] showed that the daily range of *H* is intensified over a narrow belt of ± 3° over the magnetic equator. This was attributed to a band of strong eastward current – equatorial electrojet – over the magnetic equator[2]. The first theoretical model of the equatorial electrojet was provided by Baker and Martyn[3] based on the enhancement of the electrical conductivity over the magnetic equator where the electric field is orthogonal to the magnetic field and where (*E* region of the ionosphere) the mobilities of the positive ions and electrons are different.

Besides the abnormal enhancement of the solar daily variation of *H* over the magnetic equator, various other features of the low-latitude ionosphere, viz. the solar flare effects, lunar tides, solar eclipse effects at low latitudes reflect the characteristics of the equatorial electrojet. The presence of plasma irregularities in the *E* and *F* regions of the ionosphere and the equatorial ionization anomaly are the specific results of the orthogonality of the electric field with the ionization density gradient and the magnetic field over the magnetic equator. These aspects of the equatorial electrojet have been reviewed by Rastogi[4].

The effects of the magnetic disturbances on the *H* field at low and middle latitudes consist of two components; one related to the universal time (UT) and the other to local solar time. The UT component of ΔH is associated with the onset of a magnetic storm with the arrival of solar plasma cloud, and the consequent formation of equatorial ring current around the earth, and associated magnetospheric disturbances. The local solar time component of ΔH is associated with the changes in the electric field in the ionosphere, plasmosphere or in the magnetosphere related to the solar time at the place. Moos[5] was the first to derive these two components of the geomagnetic disturbances in *H* field at Bombay. The UT component now called 'storm time variation (Dst)' is derived from the hourly means of the *H* field during number of storms with time reckoned from time of the onset of the storm. The local solar time component is derived by arranging the values of *H* according to local time for a number of disturbed days. Presently this component is derived by subtracting the average daily variation on five international quiet days (Sq) from the same averaged over five international disturbed days (Sd) and is called disturbance daily variation (SD). Sabine[6] isolated some (periodicities) in the declination data at high-latitude stations on disturbed days. This effect was seen to be larger during local summer and least during local winter and showed a dependence on sunspot numbers.

Moos[5], using the Colaba magnetic data for the period 1846 to 1905, first removed the storm time variation and then arranged the deviations of ΔH according to the local time. The resultant curve was basically a single sine wave of 24 h periodicity with a maximum at 06 local time (LT) and a minimum at 18 LT. Chapman[7] analysed the data from 12 observatories and 40 magnetic storms from 1902 to 1911 and arrived at a similar conclusion.

Vestine *et al.*[8] studied the Sq and SD variations of the northward field (*X*) at a number of stations, including for the first time, an equatorial electrojet station Huancayo. The results of Sq(*X*) and SD(*X*) variations derived from his work are shown in Figure 1. It is seen that the SD variation does not show any abnormal increase

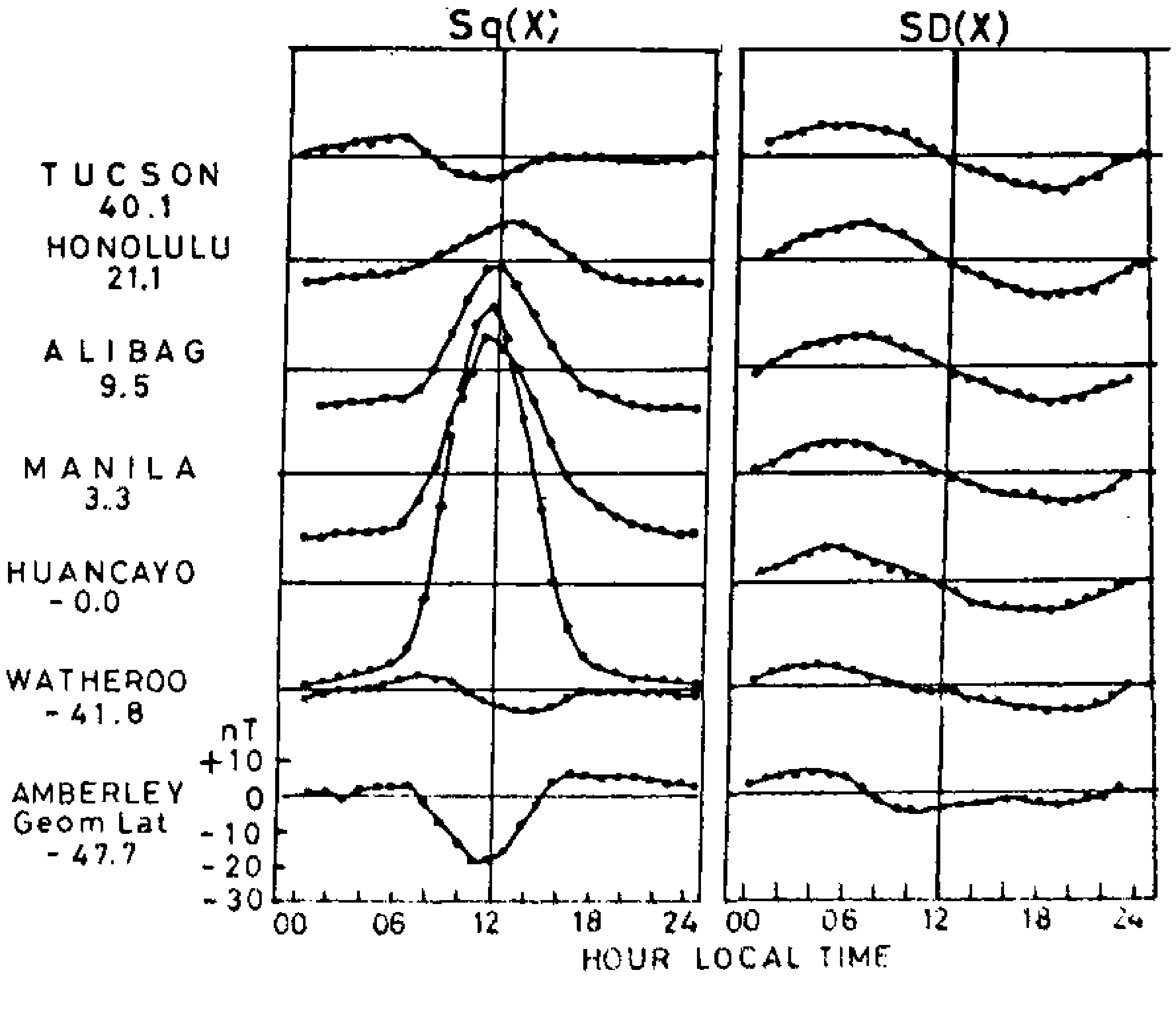

Figure 1. Solar quiet day variations (Sq) and disturbance daily variations (SD) of the northern component of the geomagnetic field (*X*) at a number of stations, after Vestine *et al.*[8].

in amplitude as Sq does. Chapman[9] had concluded that the SD(H) variation at Huancayo is normal as contrasted with the remarkable enhancement of both Sq and L. Similar conclusions have been derived by Matsushita[10], and Sugiura and Chapman[11]. It has been observed that the mid-day values of electrojet strength in Indian as well as in American sector are consistently smaller on disturbed days than on quiet days during any of the solar epoch[12]. Yacob[13] studied the SD(H) and Dst(H) variations at Indian observatories during IGY period. He found that the disturbances are of about the same magnitude during the night time at the three observatories, while during the day time disturbance magnitudes near the magnetic equator are enhanced.

The geomagnetic variations at ground level have been now identified to be the resultant of electric currents in the ionosphere, and various levels of upper atmosphere and magnetosphere together with the current induced inside the earth. There is no unique and definite method of isolating these sources from ground geomagnetic data. The ionospheric drift observations at Thumba have provided a data associated with the ionospheric electric field in the electrojet region and these data have isolated some new results. The magnitude and direction of ionospheric drift were shown to be closely related to ionospheric electric field in respect to daily or seasonal variations[14]. One of the important results was that the ionospheric drifts during the mid-day hours and hence the eastward electric field decreases systematically with increasing magnetic activity[15]. Using the ionospheric and magnetic data at Huancayo coupled with VHF backscatter radar data at Jicamarca, it was observed that sometimes during magnetic disturbance equatorial electric field during the day time does reverse to westward direction[16]. Rastogi and Patil[17] showed that ΔH at Trivandrum (TRD) minus ΔH at Alibag (ABG) at the same time is directly related with the Doppler shift of VHF back scatter radar at Thumba during quiet as well as disturbed conditions[17]. Thus ΔH (TRD − ABG) is a direct measurement of the ionospheric electrojet electric field.

In this paper ΔH at TRD and ABG on quiet and disturbed days during the period 1958–1968 have been examined to study the disturbance daily variation (SD) of the electrojet current.

The magnetic observatory at TRD (long. 77°E dip angle 1°S) is situated very close to the axis of the equatorial electrojet. The observatory at ABG (long. 72.9°E dip angle 24°N) is situated well outside the range of equatorial electrojet effects. Thus, subtracting the hourly values of ΔH at ABG from the corresponding ΔH at TRD, one gets a very precise measure of the strength and direction of the electrojet current. A positive value of ΔH (TRD − ABG) indicates an westward current at 100 km altitude. The value of ΔH (TRD − ABG) indicates a westward current at 100 km level even though the global Sq current at 106 km above the magnetic equator may still be eastward[18].

The monthly mean solar daily variations of the H field at both the stations were computed using hourly set of data from 00.5 to 24.5 UT on five international quiet (IQ) and five international disturbed (ID) days of each month. The inequalities between the first and twenty-fifth values were adjusted by distributing it throughout the day. The deviations of ΔH on IQ and ID days were computed with respect to that on 0.5 h LT. The disturbance daily variations SD(H) were computed by subtracting the Sq from the corresponding Sd variations. The monthly mean solar daily variations on ID minus Q days were averaged for the two years 1958–1959, 1960–1961, 1962–1963 and 1964–1965 for both the stations TRD and ABG as well as for TRD minus ABG. Figure 2 shows the yearly average SD variations of SD(H) at TRD, ABG and TRD − ABG for each of these epochs.

The SD(H) variation at ABG during any of the solar epochs consists of a single sine wave with a dawn maximum and a dusk minimum. The amplitude of the wave decreased progressively with the decrease of solar activity from 1958 to 1965.

The SD(H) variation at TRD also shows a dawn maximum and a dusk minimum and the range of the wave decreased progressively from 1958 to 1965. However, contrary to what is observed at ABG, the curves representing SD(H) at TRD show a very important minimum around mid-day hours during any of the years.

To ascertain whether the abnormal feature of SD(H) at TRD is a mid-day depression or an afternoon secondary maximum we examined the SD(H) of TRD − ABG. It

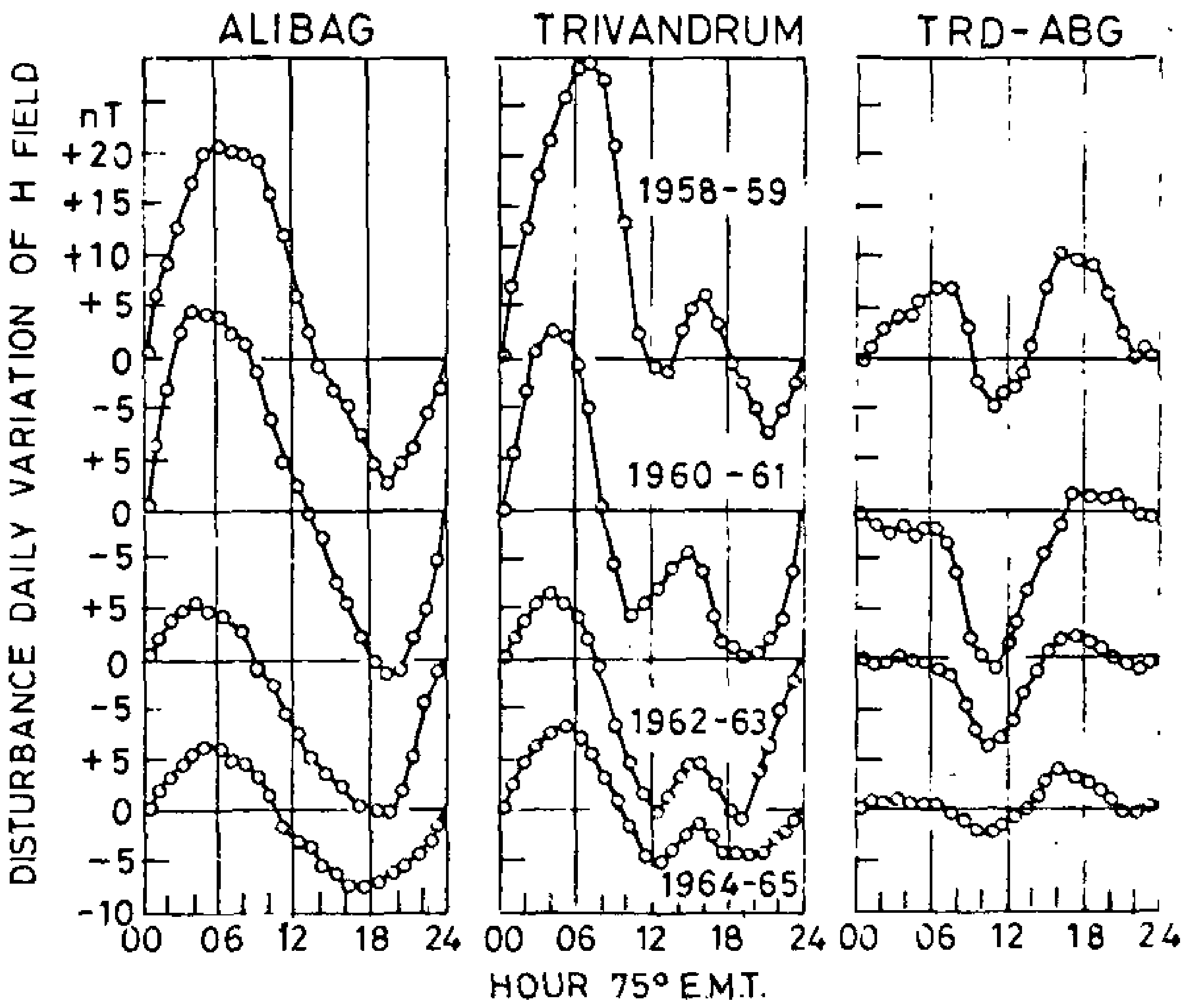

Figure 2. The disturbance daily variations of the horizontal geomagnetic field (SD, H) at Alibag (ABG), Trivandrum (TRD) and the difference SD(H) (TRD) − SD(H) (ABG) averaged for successive two year periods 1958–1959, 1960–1961, 1962–1963 and 1964–1965.

is very clear that there is a definite day time decrease of the H with a minimum at noon. This suggests that the geomagnetic disturbances are associated with the imposition of a westward electric field over the electrojet region.

Comparatively most of the studies on SD(H) variations have been made for middle- and high-latitude stations and little attention has been paid for the data at equatorial stations. The first theoretical explanation of SD(H) variation was put up by Chapman[7] as due to up and down motion of the 'ionospheric layer' whose conductivity was greater over the PM than over the AM hemisphere. Chapman[19] found that the vector diagrams of the current for stations in the auroral zone were elongated in the direction of transverse to the magnetic meridian while at other stations the curves were more or less oval. He suggested that near the auroral zone there may be considerable change of type in SD as the intensity of the disturbance increases or decreases. The auroral current zone broadens and moves toward lower latitudes during periods of intense disturbance. Stagg[20] concluded for the presence of a narrow zone symmetrically encircling the magnetic axis pole and 23° from it, the direction of this current flow being east to west in early local morning hours and in the opposite direction in the evening. McNish[21] showed that the auroral zone has a controlling and initiating influence over the world-wide electric currents responsible for SD. Bartels and Johnston[22] constructed SD graphs for seven observatories, showing the effects of season sunspot cycle and magnetic activity. Their curves did not show any enhancement of SD(H) at Huancayo as is Sq and L. Namikawa[23] obtained the current system from 45 observatories in middle and low latitudes for the second polar year. Thus, the role of auroral electrojet current in the low and middle latitudes were overwhelmingly coming through.

Akasofu and Chapman[24] showed that the growth of auroral electrojets can greatly enhance the equatorial electrojet. They suggested that part of the return current spreading from the aurora zone to the ionosphere in low and middle latitudes can extend to as far as the late afternoon side along the magnetic equator. Later Akasofu and Chapman[25] suggested that the SD variation in low latitudes is not associated with the return current of the polar electrojet. They concluded that the origin of the major part of the SD variation in low latitude is located beyond the F layer of the ionosphere.

Vestine and Chapman[26] suggested the dynamo theory of SD variation due to the wind system modified by the impact of particles of solar origin. A similar conclusion was drawn by various workers[27-29]. Cole[30] suggested that a combination of dynamo and externally generated electric field is likely to be needed in explaining the magnetic disturbance phenomena. Dungey[31] showed that SD and other magnetic disturbance phenomena might be accounted for by combining the effects of interplanetary magnetic field and the viscous interaction at the magnetopause.

It may be stressed that all these theories do not consider the enhancement of SD variation of equatorial electrojet observatories during mid-day hours. Numerous evidences are available to show that during periods of geomagnetic activity, ionospheric electric fields and current at low and equatorial latitudes are very different from those during quiet patterns[32-38]. One of the sources of the additional electric field at the low latitudes is due to the solar wind/magnetosphere interaction. The magnetic field associated with the solar plasma interacting with the magnetosphere generates $-v \times Bz$ electric field which can be communicated to high latitudes along geomagnetic field lines[39]. These electric fields penetrate directly to low latitudes through the conducting ionosphere by a process shown by Kikuchi *et al.*[40] and Kikuchi and Araki[41]. The other process could be called disturbance dynamo which could be a modern modification of the dynamo theories of the SD. Blanc and Richmond[42] described the numerical simulation of thermospheric winds produced by auroral heating during magnetic storms, and of their global dynamo effects leading to 'an ionospheric disturbance dynamo'. They suggested that the auroral heating generates equatorward winds at mid-latitudes, which make a westward motion of the atmosphere with respect to the earth. The westward wind in turn generates equatorward Pedersen currents which accumulate charges towards the equator, resulting in the generation of a poleward electric field, a westward $E \times B$ drift and an eastward current, finally resulting in an anti-Sq type of current vortex. Their suggestion of disturbance dynamo may be useful to explain the decrease of equatorial electrojet following major magnetic storms. The present analysis shows a regular westward electric field at equatorial latitudes during varying geomagnetic activity not directly related to geomagnetic storms.

It has been only due to high quality of geomagnetic data at three equatorial electrojet observatories operating since 1958 which has enabled such a conclusion of a regular westward electrojet current during geomagnetic activities. Rastogi and Chandra[43] have shown that the equatorial ionospheric drift and hence the ionospheric electric field during mid-day hours decreases uniformly with the increase of Bz component of the interplanetary magnetic field (IMF). The westward electric field opposing the normal Sq field with increasing Bz of IMF is distinctly different from the disturbance dynamo field suggested by Blanc and Richmond[42].

Finally, it may be mentioned that Hutton[44] had concluded that the disturbance daily variation of the equatorial electrojet has a maximum at noon hours, contrary to the findings of the present paper. It has been realized that Hutton had derived SD variation of the electrojet by subtracting SD(H) variation at Bangui (dip 7°S) for the year 1956 from the SD(H) variation at Ibadan (dip 2.5°S) for the year 1958. The two years had very different solar activity, and hence the geomagnetic disturbance activity, and this led to the misleading conclusions by Hutton. One has to use simultaneous data from low and equatorial stations from the same longitude sector for obtaining a correct picture of disturbance effects on the equatorial electrojet.

A systematic anti-Sq variation of the equatorial electrojet has been shown to exist during disturbed days, as earlier suggested by the ionospheric drift observations at Thumba. Similar analyses are necessary on the equatorial electrojet observations at different longitudes and to assess how much this effect is due to the disturbed atmospheric dynamo initiated by the magnetic storms.

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