

Disturbed Day Variation of Geomagnetic H-Field along the Magnetic Equator

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Abstract
The structure of the equatorial electrojet during disturbed condition is examined using data from 10 MAGDAS stations along the magnetic equator. Most of the variations occurred around noon. The trend of the variations when observed are not consistent, non-periodic and the variations were highly dispersed. The highest magnitude of the variations recorded is 185nT at Langkawi. Some regular magnetospheric activities connected to local solar time may be a potential source for the phenomenon. Counter eletrojet (CEJs) were recorded during this period. This is as a result of reversal of electric fields due to lunar tides, substorm and winds. Their amplitudes and time of occurrence varies respectively. CEJs occur during the morning hours and evening hours with intensities up to -75nT. The magnitudes of EEJ during the time of occurrence of CEJ events appreciably decreased. It was also observed that noontime peaks of EEJ is either delayed or advanced during CEJ events.
Keywords: Equatorial electrojet, Counter electrojet, Magnetic equator

1. Background

The necessity to comprehend the behavior of the Earth's magnetic field, its origin and variations in recent times is becoming very important with much research, focused on both the surface of Earth and the Sun-Earth environment. The aim is to be able to forecast the behavior of the magnetic field on Earth. The Earth's magnetic field is important for life because it forms an envelope around the planet, protecting it from high energy particles and radiation from the Sun, which can cause damage to life, power systems, orbiting satellites, astronauts, communication systems and spacecrafts (Gunnarsdottir,2002).

Geomagnetic field is the observed magnetic field on Earth cause by the interference of magnetic field produced by different sources. The main field is produced by a magnetic dynamo in the Earth's liquid core and is by far the most significant one. Field produced by the electric currents in the ionosphere and magnetosphere constitutes the external field while the field generated by the induced currents in the crust, mantle and oceans adds to the total geomagnetic field . The geomagnetic field components which make up the total geomagnetic field are: the external field, the main field and the induced field (Merrill and McElhinny,1993).

The Earth's magnetic field varies both in space and time (Auster, 2008). The time variations are divided into two main groups; long and short term variations. Other than duration, what distinguishes them is that long term variations come from the dynamics of Earth's interior while short term variations have an external origin. The long term variations are called secular variations (Lanza and Meloni, 2006). The short term variations can be on the scale of seconds or more but their duration hardly exceeds a year. They are often intense variations in the field and are mainly produced by currents in the magnetosphere and ionosphere. The speed and strength of these variations make them very obvious in magnetic observatory data. Repeated cycles of variations due to the rotation and orbital motion of the Earth, Sun and Moon are examples of short term variations. In order to portray the state of magnetic field, a variable is required and frequently used is the K-index. The K- index shows the localized intensity of the magnetic activity at an observatory where the indices are measured from the observatory recording and presented by a one- digit number in the scale 0 to 9, (Jankowski and Suckdorff, 1996).

The short term variation could be irregular or regular. Irregular variations in the geomagnetic field is caused by the interaction between the magnetic field of the solar wind and the magnetosphere. This involves the transfer of plasma and energy, which leads to time varying currents in the magnetosphere and ionosphere. Sudden and repeated (but not regular) changes in the magnetosphere are called a geomagnetic storm. Impacts of geomagnetic storm can be measured in all the latitudes.

Regular variations of the geomagnetic field are due to Earth's rotation and its orbital movement around the Sun, as well as the orbital motion of the Moon. Solar daily variations, also called diurnal variations are the most significant of the regular variation. Electric currents flowing in the E-layer of the dayside ionosphere are assumed to be the dynamics responsible for the diurnal variations (Love, 2008). Time of year, geomagnetic latitude and solar activity are factors in which regular diurnal variations depend on. The diurnal variation is only visible in the magnetogram on days when there are no stronger magnetic disturbances in the magnetosphere. These days are called solar quiet days S_q . Corresponding days, when the magnetic field is active, are called solar disturbed days S_d (Lanza and Meloni, 2006). Other forms of regular variations are Lunar variations which depends on lunar time and which are small variations of only a few nT. They occur because gravitation of the moon causes atmospheric tides, others are yearly and seasonal variations.

The simplest way for magnetic observatories to show the measurements of geomagnetic field is through a magnetogram showing a plot of the magnetic field against time.

During the daytime, eastward polarization field is generated by global scale dynamo at the magnetic dip equator which gives rise to a downward Hall current. Due to the presence of a non- conducting boundary a strong vertical polarization field opposes the downward flow of the current. This field in turn gives rise to the intense Hall current which Chapman (1951) named Equatorial Electrojet (EEJ). EEJ is indicated on a magnetogram as enhancement of the solar daily variation of the horizontal component of the magnetic field H. This current is a narrow belt of intense electric magnitude in the ionosphere confined to about $\pm 3^{\circ}$ in the dip equator. Since EEJ is an eastward current, it does not produce an eastward component of magnetic field. It has a pronounced effect on the quiet daily variation of the north component of the geomagnetic field $S_q(X)$ and on the quiet daily variation of the horizontal geomagnetic component $S_q(H)$.

The EEJ phenomenon has been studied by several scientists both in the past and recent times. Geomagnetic field variations from some Equatorial Electrojet stations along the dip equator was examined by (Adimula *et al.,* 2011). The results show that, there is variability of EEJ strength, with EEJ strongest in South American sector and weakest in Malaysian Sector. Variability of equatorial ionosphere inferred from geomagnetic field measurements by Rabiu *et al.* (2007) was also studied. It was observed that the equatorial electrojet exhibit diurnal variations on both quiet and disturbed days. Bartel and Johnson (1940) as well as Egedal (1947) discovered that the diurnal range of H at the stations near the equator peaks around the dip equator with assumption that the amplitudes of the daily variations in D and Z are not affected. Bagiya *et al.* (2009) noticed that the equatorial electrojet (EEJ) controls the magnitude and latitudinal spread of equatorial ionization anomaly (EIA), which is a function of electron density concentration. The EEJ and EIA are consequences of equatorial electrodynamics.

1.1 Disturbed daily variation

The quiet time diurnal variation of the equatorial electrojet arises primarily from irregular changes in the neutral wind trigger by meteorological forcing from the lower atmosphere (Yamazaki *et al.,* 2014a). During the periods of increase geomagnetic activity, equatorial currents and ionospheric field experience pronounced contrasts from their quiet day pattern (Fejer, 2002). Two sources have been suggested to be responsible for the generation of equatorial ionospheric effects for geomagnetically disturbed conditions. One is the frequent injection of the high latitude electric field to lower latitudes and the other is the ionospheric dynamo due to storm time thermospheric winds (Blanc and Richmond,1980). It has been shown by Rastogi (1980); Akpaneno and Adimula (2015) that disturbance daily variation of the equatorial electrojet has an anti- S_q pattern. Two components of H field are considered to be affected by magnetic disturbances at low and middle latitude. The universal time component (UT) of dH is associated with the onset of magnetic storm with emergence of solar plasma cloud, formation of equatorial ring current around the earth and associated magnetospheric disturbances. The local solar time (LT) component of dH associated with the changes in the electric field in the ionosphere, plasmosphere or in the magnetosphere related to the solar time. The UT component is referred to as storm time variation (D_{st}) and is obtained from the hourly means of the H field during number of storms estimated from the time of the onset of the storm. The local solar time component is obtained by arranging the values of H based on the local time for a series of disturbed days (Rastogi, 1997). The first theoretical explanation of S_d (H) variation was proposed by Chapman (1951) as due to up and down motion of the ionospheric layer whose conductivity was greater over the PM than over the AM hemisphere. Vestine *et al.* (1947) investigated the S_q and S_d variations of the northward field (X) at a number of stations, including an equatorial electrojet station at Huancayo. He concluded that S_d variation does not show any abnormal increase in amplitude as S_q does. Chapman (1951) observed that the mid - day values of electrojet amplitude in Indian as well as in American sector are consistently smaller on disturbed days than on quiet days. S_d (H) and Dst (H) variations at Indian observatories during IGY period were also investigated by (Yacob, 1977). It was discovered that the disturbances are of the same magnitude during the night time at the three observatories, while during the day time, disturbance magnitudes near the magnetic equator are enhanced.

1.1.1 Materials and Methods

The year 2008 magnetic data was used to achieve the desired goals. Data were obtained from Magnetic Data Acquisition System (MAGDAS). The MAGDAS system records data every second. Minutes averages of the horizontal intensities from 10 stations along the dip equator were used. Table 1 shows the basic parameters of the station while figure 1 presents the locations of the observatories.

The international disturbed days (IDDs) were selected and used through the analysis. These days are the five (5) disturbed days based on magnetic activity index K_p. These days were published by Geosciences Australia (2013). The concept of local time is used throughout the analysis. The mean hourly values or the variation baseline is obtained from the 2 hours flanking local midnight. (Details explained by Rabiu et al. 2007). The disturbed daily variation S_d was derived by subtracting the average of S_q of five international quiet days from average daily variation of five international disturbed days.

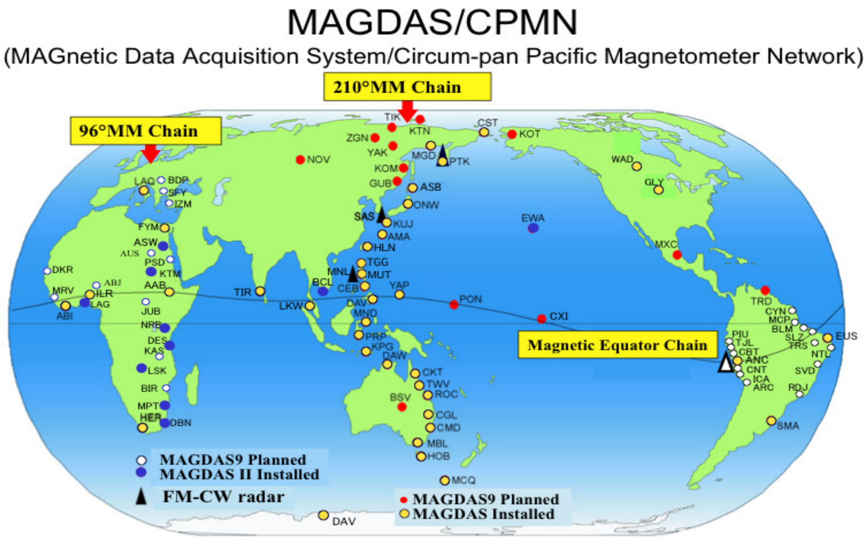

Figure 1 The global network of the MAGDAS magnetometers (Yumoto and MAGDAS group, 2007)

Table 1: Parameters of the station used in the study

S/N	STATIONS	Code	Geographic latitude	Geographic longitude	Geomagnetic Latitude	Geomagnetic Longitude	Dip latitude
1	Ilorin	ILR	8.50	4.68	-1.82	76.8	-2.96
2	Lagos	LAG	-6.48	3.27	-3.04	75.33	-4.95
3	Ancon	ANC	-11.77	-77.15	0.77	354.53	0.74
4	Davao	DAV	7.00	125.40	-1.02	195.54	-0.65
5	Eusebio	EUS	-3.88	-38.43	-3.64	34.21	-7.03
6	Yap Island	YAP	9.50	138	1.49	209.06	1.70
7	Addis Ababa	AAB	9.04	38.77	0.18	110.23	0.57
8	Lang kawi	LKW	6.30	99.77	-1.23	170.06	-0.47
9	Cebu	CEB	10.36	123.91	2.53	195.06	2.74
10	Triunelvelli	TIR	8.50	77.0	-1.2	146.4	-0.2

1.1.2 Results

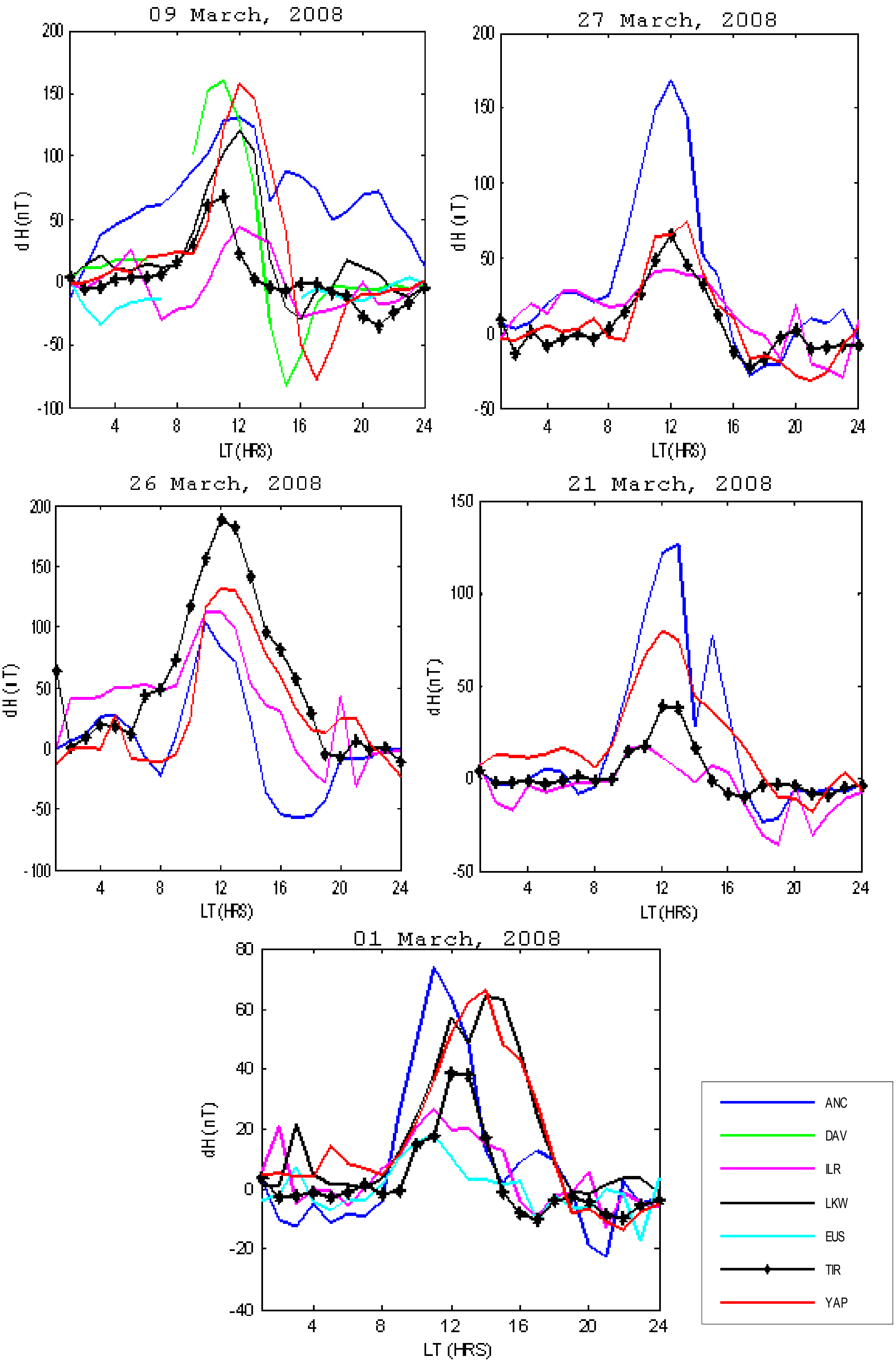

Fig. 2a: Disturbed day variation of the horizontal component of the magnetic field dH for March 09, 27, 26, 28 and 01, 2008.

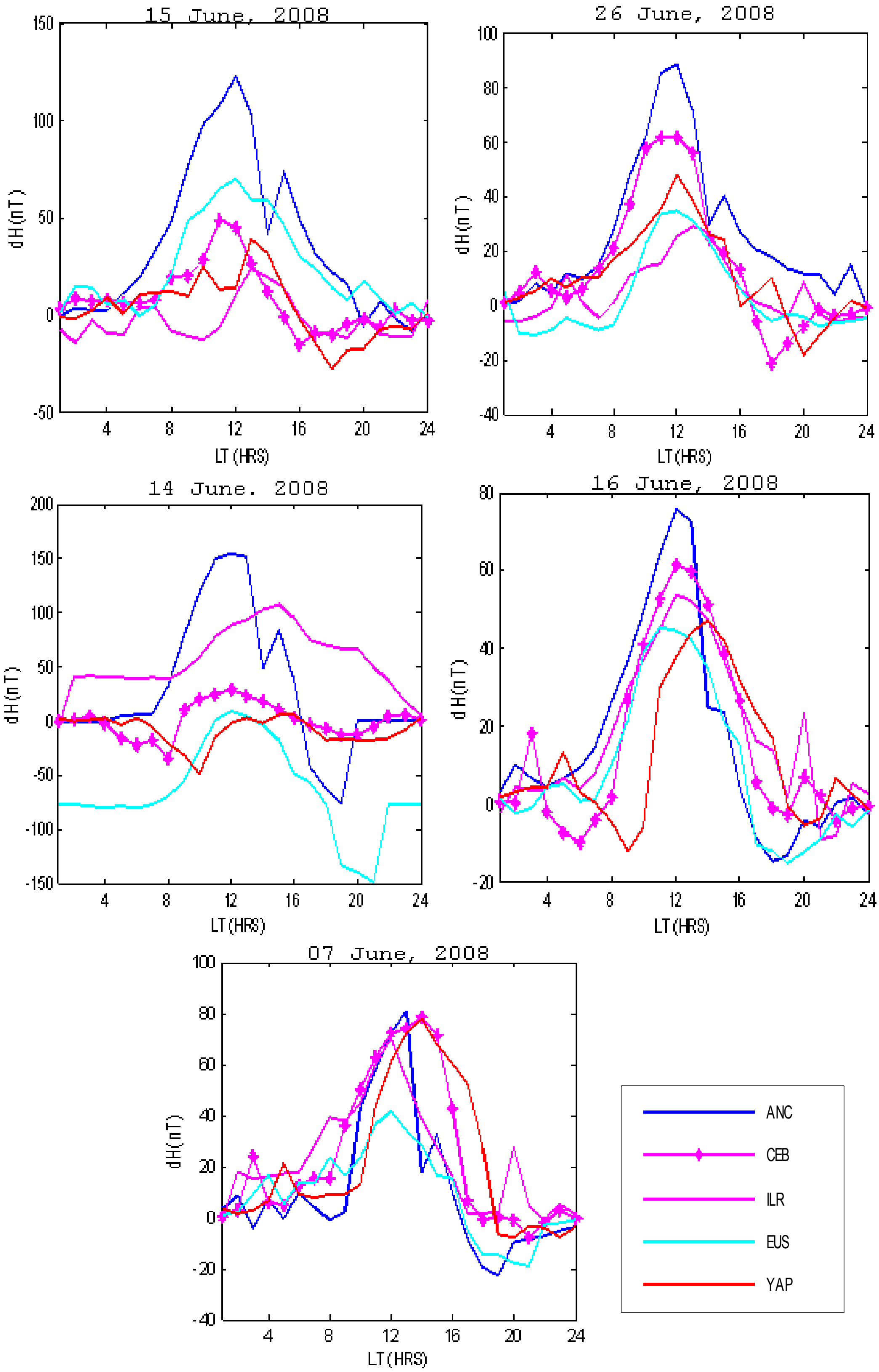

Fig. 2b: Disturbed day variation of the horizontal component of the magnetic field dH for June 15, 26, 14, 16 and 07, 2008.

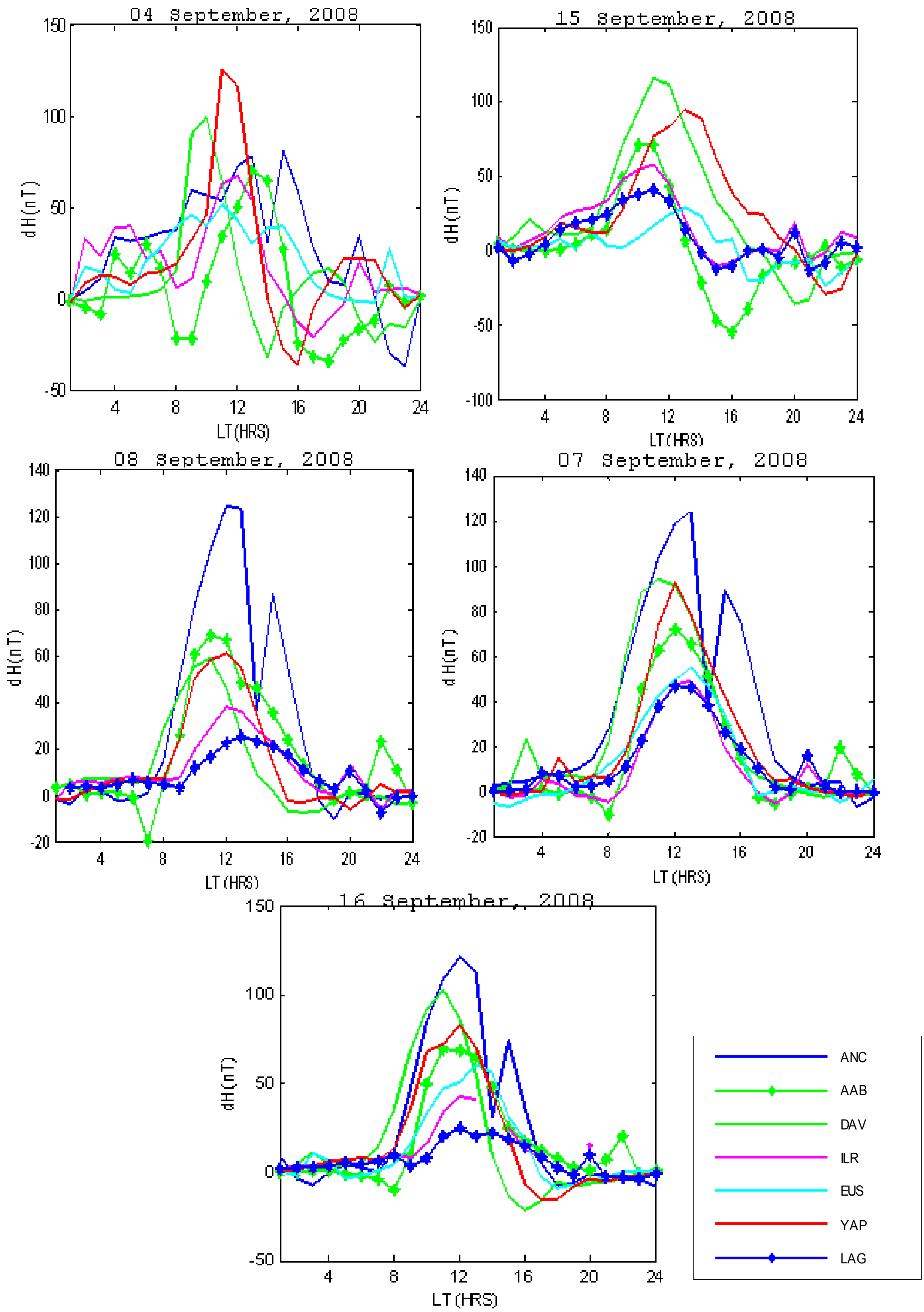

Fig. 2c: Disturbed day variation of the horizontal component of the magnetic field dH for September 04, 15, 08, 07 and 16, 2008.

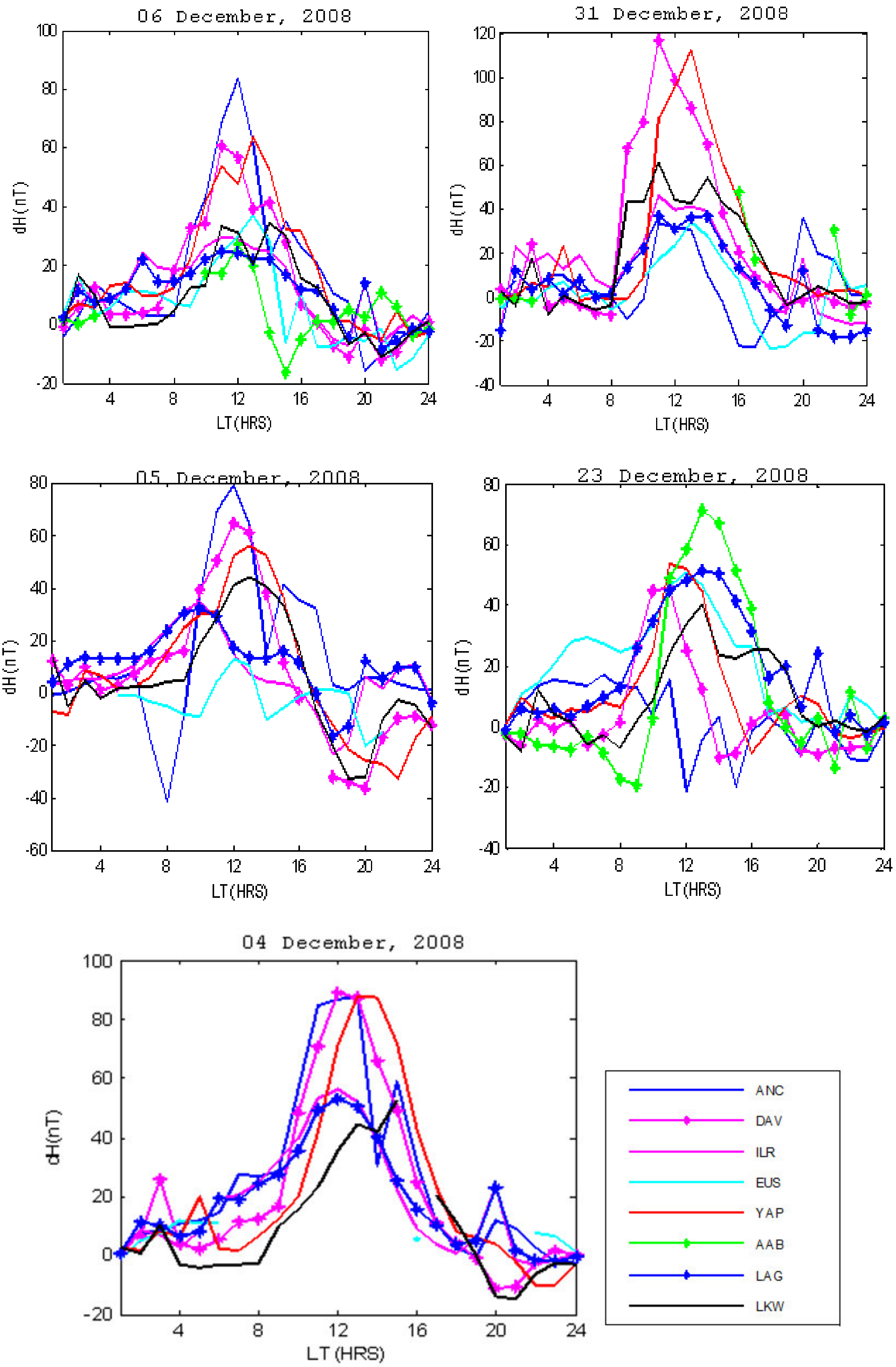

Fig. 2d: Disturbed day variation of the horizontal component of the magnetic field dH for December 06, 31, 05, 23 and 04, 2008.

1.1.3 Discussion

The variation during disturbed condition S_d is another solar daily variation in the magnetic activity period with a sinusoid variation of H component as its prominent character. S_d is common at high latitudes, most significantly around the aurora zone. During disturbed period, the amplitude of S_d in low and middle latitudes increases significantly. Chapman and Bartels (1940) obtained equivalent current system of S_d variation, pointing out that S_d was likely created by the return current of the substorm wedge in low latitude ionosphere. The variations of S_d depend on local time (LT) and its assume space-time characteristics. Geomagnetic disturbances is associated with the imposition of a westward electric field over the electrojet region. Hence, the combination of the increase in the solar wind speed and the changes in IMF's intensity and dynamics influence the geomagnetic field conditions in such a way that a geomagnetic disturbance emerge.

The daily variation of the H component of the geomagnetic field under disturbed condition was examined. The year 2008 (a year of low solar activity) was used in the study and the results were highlighted in figure 2.

The trend of the variations when observed are not following a regular and consistent pattern. In March the variation is between 18 to 195nT; range is 177nT, for June, variation is between 10 to 125nT; range is 115nT, for September variation is 15 t0 130nT; range is 115nT and for December, variation is between 15 to 120nT; range is 105nT. The variation have a complex structure and disorganised. This result is in line with the work of Rastogi (1997) who established that during the period of geomagnetic activity, ionospheric electric fields and current at low and equatorial latitudes are very different from those during quiet pattern. The inconsistency in the pattern of variation could be attributed to ionospheric disturbance emanating from external source such as space weather effects, storm and during period at various stations differ.

The unexpected and evasive nature of counter electrojet (CEJ) events make a confident physical appearance during these period of study. Their amplitudes and time of occurrence differ during this period. These results show that CEJs appear during morning hours and evening hours. It occurs more in the evening than the morning hours. In figure 2a, on 09/03, CEJs occur at DAVAO and YAP respectively. Their amplitudes ant time of occurrence were -75nT, -70nT and 1500LT, 1700LT respectively. CEJ was also recorded on 26/06 (fig. 2b) at CEB with amplitude of -20nT and the time is 1700LT. On 08/09 CEJ with amplitude of about -20nT at 0700LT was also recorded at AAB. It was observed that the noontime peaks of EEJ is either delayed or advanced during the CEJ events. For instance, the occurrence of CEJ events on 09/03 delayed EEJ to 1100LT at DAVAO while at ILR, EEJ was advanced to 1200LT. Hence, the EEJ variations at any stations could be affected by CEJ events. There is also variability in the occurrence of CEJs. This result is in line with the observations made by Kikuchi et al. (2003) and McCreadie, (2004).

1.1.4 Conclusion

The study was aimed at examining the strength of the geomagnetic field variation under disturbed conditions in some selected geomagnetic observatories along the magnetic equator. The data employed was 2008 (year of low solar activity). The daily variability of the H component of the geomagnetic field during disturbed conditions is different from the normal quiet day pattern. It is inconsistent and disorganised. March equinox is observed to exhibit higher variability of 177nT when compared to solstice months. The inconsistency in the trend of the variation could attributed to ionospheric disturbances emanating from external source such as space weather effects, storm and partly in the magnetosphere. Series of counter electrojet (CEJs) were recorded during the disturbed periods. This is as a result of reversal of electric fields due to lunar tides, and localized winds.

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References

Adimula, I.A., Rabiu, A. B., Yumoto, Y. and the MAGDAS Group (2011). Geomagnetic Field variations from some equatorial elctrojet stations. Sun and Geosphere, 6(2): 45-49.

Akpaneno, A. F. and Adimula, I. A. (2015). Variability of H component of the Geomagnetic Field from some equatorial electrojet stations. Sun and Geosphere 10: 65-77

Auster, H. U. (2008). How to measure Earth's magnetic field Physics Today, 61(2). 76-77

Babatunde, R. (2011). The Equatorial ionosphere, A tutorial. National Space Research & Development Agency (NASRDA), Abuja, Nigeria.

Bagiya, M. S., Joshi, H. P., Iyer, K. N., Aggarwal, M., Ravindran, S., Pathan, B. M. (2007). TEC variations during low solar activity period (2005-2007) near the equatorial ionospheric anomaly crest region in India. Ann. Geophys. 27, 1047-1057.

Bartels, J. and Jonson, H. F. (1940). Geomagnetic tides in horizontal intensity at Huancayo. Part 1. J. Geophys. Res., 45: 246-308

Blanc, M. and Richmond, A. D. (1980). The ionospheric disturbances dynamo, J. Res. 85, 1669- 1686.

Chapman, S. (1951). Some phenomena of the upper Atmosphere, proceedings of the physical society of London B, vol. 64, 833-843
Chapman, S. and Bartels, J. (1940). Geomagnetism, Oxford, Oxford University Press.
Egedal, J. (1947). The magnetic diurnal variation of the horizontal force near the magnetic equator. Terr. Magn. Atmos. Electr.,52: 449-451
Ferjer, B. G. (2002). Low latitude storm time ionosphere electrodynamics, J. Atmos. Sol. Terr. Phys. 64, 1401-1408
Geoscience Australia, (2013). Tabulated IQDs and IDDs data. www.ga.gov.au
Gunnarsdottir, E. L. (2012). The Earth's Magnetic Field Physics Department, School of Engineering and Natural Sciences, University of Iceland.
Jankowski, J. and Suckdorff, C. (1996). Guide for magnetic measurements and observatory practice. Warszawa: International Association of Geomagnetic and Aeronomy.
Kikuchi, T., Hashimoto, K. K., Kitamura, T.I., Tachihara, H. and Fejer, B. (2003). Equatorial counter electrojets during substorms. J. Geophys. Res. 108
Lanza, R and Meloni, A. (2006). The Earth's magnetism. An introduction for Geologist. Wurzburg: Springer.
Love, J. J. (2008). Magnetic monitoring of Earth and space Physics Today, 61 (2). 31-37.
McCreadie, H. (2004). Classes of the equatorial electrojet. Earth observation with CHAMP; results from three years orbit springer, Berlin, pp 401-406
Merrill, R. T. and McElhinny, M. W. (1993). The Earth's magnetic field-Its History, origin and planetary perspective. Orlando: Academic Press, Inc.
Rabiu, A.B., Mamkuyomi, A.I. and Joshua, E. O. (2007). Variability of equatorial ionosphere inferred from geomagnetic field measurements. Bull. Astr.Soc.India, 25607-618.
Rastogi, R. G. (1997). Disturbance daily variation of equatorial electrojet current. Res. Comm.
Rastogi, R.G. (1980). Seasonal variation of equatorial spread F in the American and Indian zone. J. Geophys. Research.
Vestine, E. H., Laporte, L., Lange, H. and Scott, W. E. (1947). The Geomagnetic Field and its application/Anaysis, C. I. W. Publ. No. 580
Yacob, A. (1977). Internal induction by the equatorial electrojet in India examined with surface and satellite geomagnetic observations. J. Atmos. Terr. Phys. 39, 601-603.
Yamazaki, Y., Richmond, A. D., Mante, A., Liu, H. L., Pedatella, N. and Sassi, F. (2014a). On the day to day variation of Equatorial electrojet during quiet periods, J. Geophys. Res. Space Physics, 119, 6966 -6980.