Observation of Large-Scale Traveling Ionospheric Disturbance over Peninsular Malaysia Using GPS Receivers

Intan Izafina Idrus, Mardina Abdullah, Alina Marie Hasbi, Asnawi Husin

Abstract**—**This paper presents the result of large-scale traveling ionospheric disturbance (LSTID) observation during moderate magnetic storm event on 25 October 2011 with SYM-H ~ -160 nT and Kp ~ 7 over Peninsular Malaysia at equatorial region using vertical total electron content (VTEC) from the Global Positioning System (GPS) observation measurement. The propagation of the LSTID signatures in the TEC measurements over Peninsular Malaysia was also investigated using VTEC map. The LSTID was found to propagate equatorward during this event. The results showed that the LSTID propagated with an average phase velocity of 526.41 m/s and average periods of 140 min. The occurrence of this LSTID was also found to be the subsequent effects of substorm activities in the auroral region.

Keywords**—**Global Positioning System (GPS), large-scale traveling ionospheric disturbance (LSTID), moderate geomagnetic storm, vertical total electron content (VTEC).

I. Introduction

LARGE-SCALE traveling ionospheric disturbances (LSTIDs) are ionospheric manifestation of atmospheric gravity waves (AGWs) generated by high-latitude sources such as Joule heating, Lorentz forces and particle precipitation [1]. The phenomenon of LSTIDs had been studied by researchers since four decades ago [2]. LSTIDs were reported to have wavelengths of more than 1000km, phase velocities of 300-1000m/s and occurs between 30min and 3 hours [3]. These disturbances play an important role in the dynamics of the thermosphere as LSTIDs propagate away from the source region and leading to the global energy redistribution [4].

LSTIDs can be observed by various measurement techniques such as ionosonde [5], incoherent scatter radar [6], HF Doppler [7] and airglow imager [8]. Recently, many studies reported the use of Global Positioning System (GPS) to study LSTIDs [5], [9]-[13]. Research on LSTIDs has become significant due to the fact that these ionospheric disturbances may affect satellite communication and navigation systems. Reference [14] investigated the form and dynamics of LSTIDs during a strong magnetic storm on 25 September 1998 in North America using ground-based GPS arrays. They found that the LSTIDs propagated equatorward with mean velocity of 300 m/s. Reference [10] studied magnetic conjugacy of LSTIDs using the GPS Earth Observation Network (GEONET) and International GNSS Service (IGS) in Japan and Australia, respectively. They found that the LSTIDs observed simultaneously over both Northern and Southern hemispheres are not connected electromagnetically through the magnetic field but the AGWs were propagating to the equator independently in both hemispheres. The LSTIDs were simultaneously observed in both Northern and Southern hemispheres during the sudden storm commencement (SSC) but vanished in the Southern hemisphere during the recovery phase of the storm. The hemispheric asymmetric response of the F-region was attributed to presence of different mechanisms for the generation of equatorial spread-F along the various latitudinal regions during the disturbed period. Reference [12] observed the propagation of LSTIDs during the super magnetic storm of 29 and 30 October 2003 over North America in the GPS total electron content (TEC) measurements. These LSTIDs propagated southwestward in less than 2 hours with a front width about 4000 km. LSTIDs were also observed by [13] in the TEC measurements over North America, Europe and East Asia during magnetic storm of 7 to 10 November 2004 with mean horizontal phase velocity of 350 to 550 m/s but the propagation azimuths of LSTIDs were found to be dependent on latitudes and as they tended to deflect more to west from south as they propagate to lower latitudes. The source regions of LSTIDs were located between 68°N to 62°N and 65°N to 57°N as observed using magnetic H component.

The main purpose of this paper is to contribute to the knowledge of the LSTID occurrence at equatorial region in Peninsular Malaysia. This paper aims at investigating the equatorward propagating LSTID during moderate magnetic storm of 25 October 2011 over Peninsular Malaysia using vertical TEC (VTEC) from the GPS observation measurement. It also attempts to investigate the propagation of the LSTID signatures in the GPS TEC measurements using VTEC map.

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II. Data and Method

A. Data

In this study, data obtained from the Malaysia Real Kinematics GNSS Network (MyRTKnet) network belonging to the Department of Survey and Mapping Malaysia (*Jabatan Ukur dan Pemetaan Malaysia*, JUPEM) were used to investigate the occurrence of LSTID. Fig. 1 presents the locations of GPS receiver stations over Peninsular Malaysia.

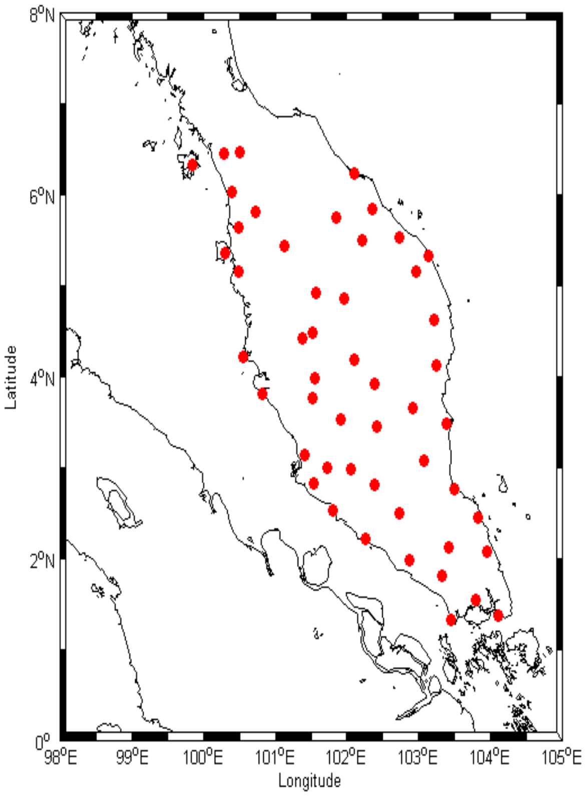

Fig. 1 Location of GPS receiver stations in the equatorial region

B. Method

The Receiver Independent Exchange (RINEX) data produced by the GPS receiver stations were processed using GPS Toolkit (GPSTk) software developed by Applied Research Laboratories of the University of Texas at Austin. For the detailed TEC data processing, readers are referred to [15]. In this work, only VTEC measurements with the elevation angle greater than 35° were utilized to avoid multipath effect and elevation angle dependence.

To identify the occurrence of LSTID, the VTEC data were detrended by fourth-order high-pass Butterworth filter. This filter was designed to eliminate the regular ionosphere effects. The maximum amplitude detrended VTEC (dVTEC) must exceed 0.5 TECU (1 TECU = 10^{16} electrons/m^2) within the LSTID period of 30 min to 3 hours. According to [10], this limit was defined to detect the occurrence of LSTID. Fig. 2 shows the detrended VTEC data by fourth-order high-pass Butterworth filter. The wave propagation parameters of the LSTID such as the phase velocity and direction are obtained by performing a cross-correlation analysis of the relative change in the VTEC between stations was introduced by [16] that include Doppler effect as shown in (1)–(3):

Assuming that the TID propagated as a planar wave for an instant time, t and a pierce point, $\boldsymbol{r}_{IPP}$:

$$\delta VTEC(t, \boldsymbol{r}_{IPP}) = F(\omega t - \boldsymbol{k} \cdot \boldsymbol{r}_{IPP}) \quad (1)$$

where F is an arbitrary function, ω is the frequency, and $\boldsymbol{k}$ is the propagation vector, the slowness, $\boldsymbol{s}$ defined as $\boldsymbol{s} = \boldsymbol{k}/\omega$, $\delta VTEC$ can be expressed as:

$$\delta VTEC(t, \boldsymbol{r}_{IPP}) = \omega \cdot F(t - \boldsymbol{s} \cdot \boldsymbol{r}_{IPP}) \quad (2)$$

By looking for the correlation between these ionospheric disturbances for different receivers, the temporal delay for maximum correlation, dt_{max} between two receivers is given as below:

$$dt_{max} = (d\boldsymbol{r}_{IPP} + dt_{max} \cdot \boldsymbol{v}_{IPP} \cdot \boldsymbol{s}) \quad (3)$$

where $d\boldsymbol{r}_{IPP}$ is the relative vector between its pierce points and $\boldsymbol{v}_{IPP}$ is the relative moving velocity.

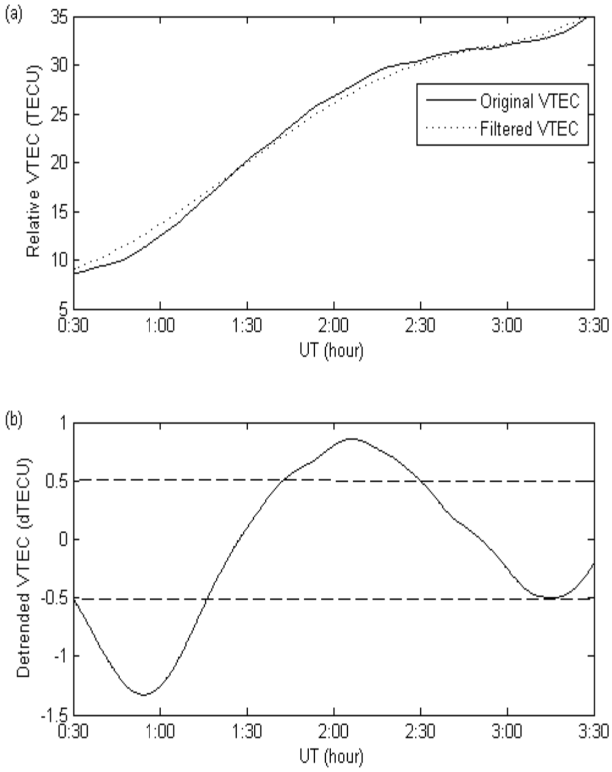

Fig. 2 (a) Original and filtered VTEC obtained using the fourth-order Butterworth high pass filter designed to filter out the low frequency VTEC for PRN 1 on 25 October 2011 and the (b) detrended VTEC obtained by subtracting the filtered VTEC from the original VTEC. The horizontal dotted line indicates the threshold of 0.5 acting over the detrended VTEC

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In order to verify the source of the occurrence of LSTID, the H-component magnetic field from five INTERMAGNET magnetic observatories located at Russia, Kazakhstan, China, Vietnam and India were analyzed. The H-component data were detrended using the same method as VTEC data. The LSTID propagation parameters were also calculated.

III. Result and Discussion

A. Magnetic Condition

During the October 2011 magnetic storm event, the magnetic and interplanetary magnetic field (IMF) Bz component obtained from the SPIDR (http://spidr.ngdc.noaa.gov/spidr), WDC (http://swdcwww.kugi.kyoto-u.ac.jp) and NOAA (http://www.swpc.noaa.gov) databases, respectively were examined to investigate the relation of magnetic activity and the occurrence of LSTID. Fig. 3 presents the magnetic indices IMF Bz component, SYM-H, Kp, auroral electrojet (AU and AL) during the 24 and 25 October 2011 magnetic storm event. The time of the SSC and periods of the main and recovery phase of the storm are also marked in the figures.

As shown in Fig. 3, the IMF Bz on 24 October 2011 turns southward at about 17:49 UT and reaches a minimum of -10 nT during the main phase before it starts recovering to its normal phase 6.8 hours later. The SSC occurred at 18:30 UT when the SYM-H index starts to decrease and reaches its minimum of -160 nT at 1:20 UT. About 17 hours after this time, the SYM-H index recovers to its normal level at 18:08 UT. During the main phase of the storm, the Kp index records a value of 7. About one hour after SSC, two substorms occurred with AL index began to drop abruptly at 19:30 UT and 0:02 to value of -1011 nT and -1054 nT, respectively during main phase. Meanwhile, during recovery phase three substorms occurred at 3:52 UT, 6:05 UT and 8:37 UT with the AL index value of -1060 nT, -824 nT and -813 nT, respectively. The observed magnetic field levels for this day were classified by IPS as “quiet to minor storm” (http://www.ips.gov.au). The occurrence of LSTID during this event was observed during the period of 0:00-4:00 UT, which falls within the period of the main and recovery phase. From these observations, the occurrence of LSTID at equatorial region has a high correlation with magnetic activity.

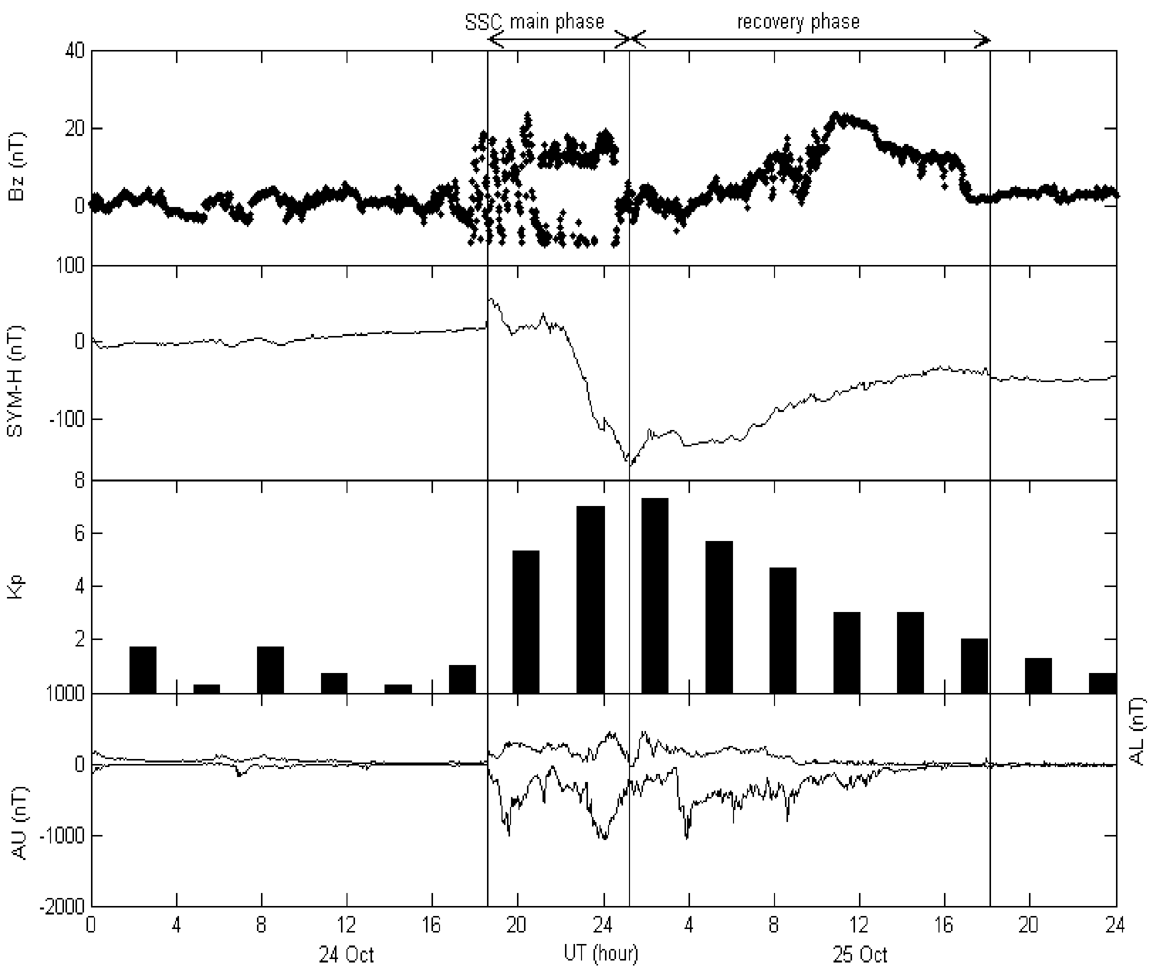

Fig. 3 The magnetic indices IMF Bz component, SYM-H, Kp, AU and AL on 25 October 2011

B. LSTID Observation during October 2011 Magnetic Storm

In the analyse, the temporal variations of the detrended GPS VTEC along individual satellite passes during the 25 October 2011 magnetic storm event is examined in Peninsular Malaysia. To analyze the spatial variations of this LSTID, the detrended VTEC are represented as a VTEC map. The propagation parameters of the LSTID for Peninsular Malaysia are obtained using (3).

Fig. 4 shows the temporal variations of the detrended VTEC during the 25 October 2011 storm over Peninsular Malaysia observed by PRN 1 at TLOH, KLAW and JUML stations from 0:00 to 4:00 UT (8:00-16:00 LT, LT leads UT by 8 hours). As shown in the figure, the LSTID is observed as wave structures consisting of a series of VTEC enhancement-depletion. These VTEC oscillations have average amplitude of 2 TECU and periods of 143 min. The phase lag of this LSTID is distinguished as increasing delay of the dip in the VTEC oscillations. According to the phase lag and (3), the wave structure over the Peninsular Malaysia moved equatorward from TLOH to JUML with average phase velocity of 526.41 m/s.

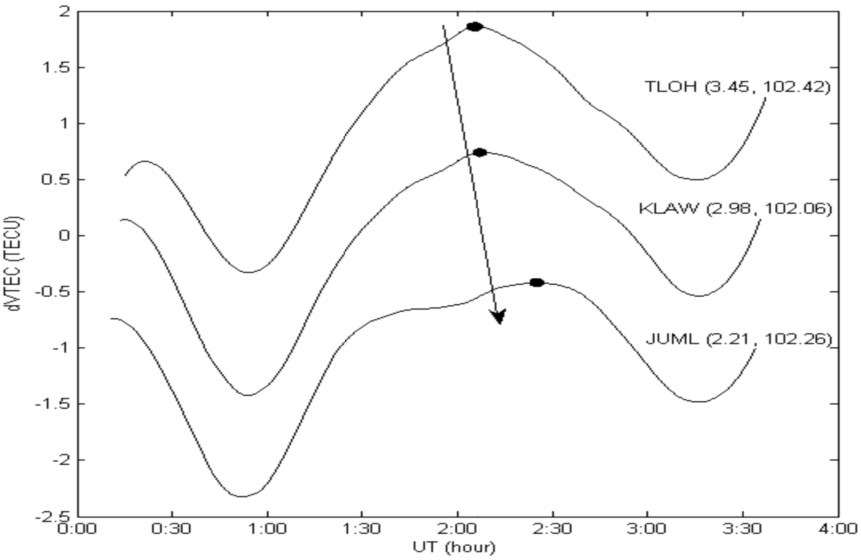

Fig. 4 Temporal variations of the detrended VTEC observed by PRN 1 between 0:00 and 4:00 UT at several stations at several stations over Peninsular Malaysia during the 25October 2011 magnetic storm

Fig. 5 presents the VTEC map over Peninsular Malaysia observed by PRN 8 on 28 May 2011 for four observation periods, which are 1:00-2:00 UT, 2:00-3:00 UT, 3:00-4:00 UT and 4:00-5:00 UT, respectively. As shown in this figure, it is observed that the LSTID over the Peninsular Malaysia propagated in the southeast direction towards the equator during the period between 1:00 and 3:00 UT. After this time, the LSTID gradually disappear.

In general our results during this event is in close agreement with previous results observed in the high and low latitudes of the Northern hemisphere during major magnetic storm events with average amplitude of around 2 TECU, average velocity ranging from 400-1200 m/s and period of about 1 hour [12], [17]-[19]. As observed earlier in Figs. 3, 4, the LSTID seen on 25 October 2011 propagated equatorward from higher to lower latitudes. It is suggested that the equatorward propagating direction was caused by the transporting energy of AGWs generated by the poleward neural wind in the auroral zone, thus pushing the plasma downward along the magnetic field line to the low-latitude ionosphere [1], [8]. The VTEC experiences temporal enhancement due to the loss of plasma in the ionospheric layer and this process propagates equatorward associated with the equatorward motion of the AGW that causes the poleward wind enhancement [8]. Reference [18] described that the LSTIDs are excited by sudden heating of the thermosphere and cause strong changes in the pressure and thermospheric wind circulation system. These may generate AGWs and LSTIDs are observed due to the changes of the strength of the wind and pressure. This mechanism needs equatorward winds that uplift the ionospheric plasma along the magnetic field lines and cause equatorward propagating LSTID as observed in our result [18].

Fig. 6 shows the H-component magnetic field during magnetic storm event of 24 and 25 October 2011 at five magnetic observatories to verify the source of the occurrence of LSTID. Several substorm events seen as negative peaks were initiated around UT on 24 October 2011. Following this time, small waves of amplitude of about 50 nT were observed during the period of the LSTID event observed by GPS VTEC from 0:00-4:00 UT on 25 October 2011. These waves moved southward with average velocity of 355.15 m/s within 105 min.

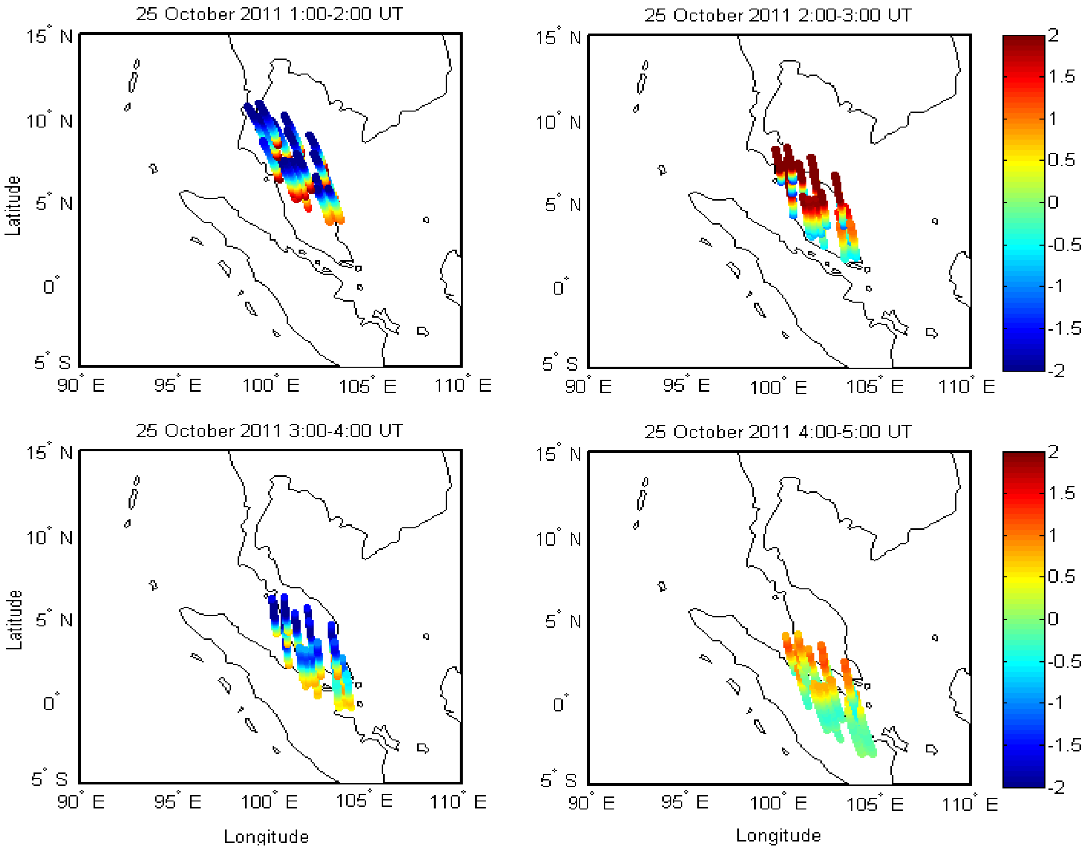

Fig. 5 VTEC map over Peninsular Malaysia for PRN 7 from 1:00 to 5:00 UT on 25 October 2011

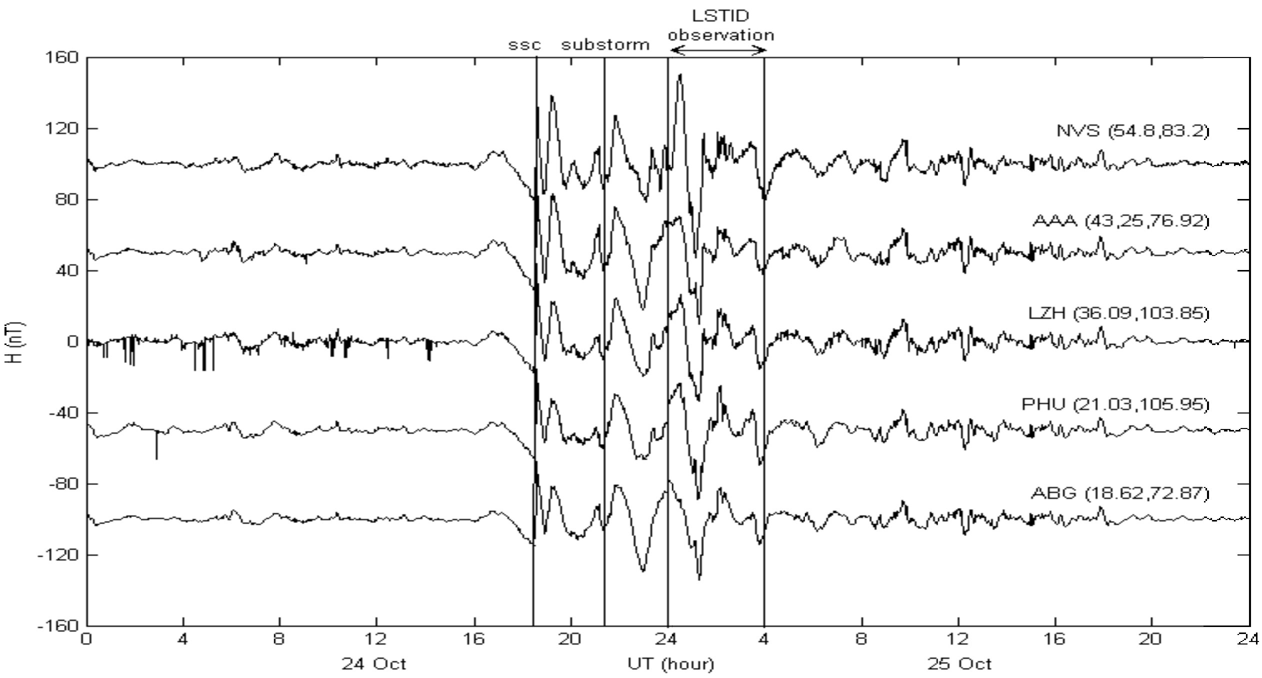

Fig. 6 The detrended H-component magnetic field on 24 and 25 October 2011 at several magnetic observatories

IV. Conclusion

We have presented the results of LSTID observation during moderate magnetic storm event in October 2011 over the equatorial region in the Peninsular Malaysia using VTEC from the GPS observations measurement. The results showed that during the 25 October 2011 magnetic storm event the equatorward movement of LSTID was found at Peninsular Malaysia with average phase velocity of 526.41 m/s and periods of 143min. The occurrence of this LSTID was also found to have high correlation with magnetic activity at high-latitudes. To provide a better understand in the generation and mechanism of this LSTID over Peninsular Malaysia, more observational data and other instruments measurement are needed.

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