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Full Length Research Paper

CHARACTERISTICS OF GEOMAGNETIC FIELD VARIATIONS OVER NORTHERN ISLAND OF MALAYSIA

Bonde, D.S Abbas M[1], Mohammad B. K[1], Yoshikawa A[2] and MAGDAS/CPMN Group[2]

[1]Department of Physics, Kebbi State University of Science and Technology, Aliero, Nigeria
[2]International Center for Space Weather Science and Education (ICSWSE), Kyushu University, JAPAN

Corresponding Email: danladibonde@gmail.com

Abstract: The magnetic records obtained at low latitude geomagnetic observatory of Langkawi for the period of 3 years was used to study the diurnal and monthly-mean variation of the horizontal and vertical component of the Earth magnetic field during quiet and disturbed conditions. Results revealed that SqH and SqZ with their corresponding disturbed variations (SdH and SdZ) shows minimum values at nighttime (18:00-05:00 LT) that are lower than the pre-sunrise (05:00-07:00 LT) magnitudes. On quiet conditions, the SqH shows a daytime linear increase from 155 nT in 2011 to 160 and 162 nT in 2012 and 2013. The disturbed period exhibit irregular variation pattern with highest values 227, 215 and 237 nT in 2011, 2012 and 2013 respectively. The daytime maximum MSqH values increase from 125 nT in 2011 to 135 nT in October 2013, in contrast to MSdH that decrease progressively from 166 nT in September 2011 to 145 nT in March 2013. The daytime maximum SqZ and SdZ with their monthly-mean (MSqZ and MSdZ) readily conform to those amplitude variations pattern with lesser magnitudes. The daytime maxima of SqH with their MSqH were observed to occur around (10:00-12:00 LT) hours and shifted to 14:00 LT during disturbed period indication of modification of electric field during disturbed period.

Keywords: Magnetic records and lesser magnitudes.

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Introduction

The continuous monitoring of the Earth's geomagnetic field at different latitudes across the world over the years is of utmost importance and revealed some outstanding changes that are regular in some days and irregular at other times. These changes in geomagnetic field are linked to two different physical mechanisms: the regular variations been directly related to the dynamo processes in the E-region of the ionosphere e.g. Mazaudier and Blanc (1982) and the irregular variations that are mostly related to the response of the magnetosphere activities Vassal *et al.,* (1998). The characteristics of the regular daily variations over India, West Africa and Brazilian region have been earlier described by Arora *et al.,* (1993); Doumouya*et al.,* (1998) and Rigoti*et al.,* (1999). Equatorial electro jet (EEJ) is mainly a daytime enhanced eastward current driven by the vertical Hall polarization electric field at the height ~100 to 110 Km in the E-region of the ionosphere resulting in significant amplification of horizontal magnetic field within ±3° geomagnetic latitudes Yamazaki and Maute (2016). Recently Yamazaki et al. (2014) reported that irregular variations in the neutral wind generate variability in the daily range of SqH near the magnetic equator and cause the electro jet current to vary from one quiet day to another. The equatorial electro jet current (EEJ) sometimes reverses its direction and flow westward at any particular hour of the day. Early works of Rastogi (1974) describe the phenomenon as an equatorial event within a certain longitudinal limit that is mostly observed in the morning and evening hours. The Sq variation of the vertical (Z) component which represents the spatial gradient of the horizontal intensity is zero at the equator and minimum/maximum at the northern/southern peripheral region of the electro jet belt. To the best of our knowledge and the result of Abbas et al., (2019) used similar magnetic field record that will be engaged in this study no detail report on the daily variations of the morphology solar quiet (Sq) and solar disturbance (Sd) variations of horizontal and vertical component of the Earth magnetic field have been reported over the Malaysian ionosphere. In this view, this study set to investigate the solar daily variations of geomagnetic field H and Z components during quiet and disturbed conditions.

Data Source

The used horizontal (H) and vertical (Z) components of the Earth magnetic field obtained from Magnetic Data Acquisition System (MAGDAS) network at Langkawi (geographic latitude: 6.3^{0}N, geographic longitude: 99.68^{0}N, geomagnetic latitude: -2.32^{0}S geomagnetic longitude: 171.29^0) during quiet and disturbed periods. Five most quiet and disturbed days of each month whose magnetic field records are used in the study are obtained from Geosciences Australia catalogue at http:// www.ga.gov.au/oracle/geomag/iqd_form.jsp.To thoroughly explore the geomagnetic field in terms of solar terrestrial activity, 3 years (2011, 2012 and 2013) data were used in the study.

3.0 Method of Data Analysis

The magnetometer fluxgate records seconds and minute magnetic field values and only the minute averaged records were used in the study. The field records which composed of 1mins averages were binned to hourly values and this reduced the data to 24 hourly values for each particular day. This was done for each day through the years under investigation. The baseline was defined as the average of four flanking local midnight (0000LT, 0100 LT, 2200 LT and 2300 LT) respectively. This is expressed as:

$$\mathrm{H_b} = \frac{\mathrm{H_{0000}} + \mathrm{H_{0100}} + \mathrm{H_{2200}} + \mathrm{H_{2300}}}{4} \quad 1$$

$$Z_{\mathrm{b}} = \frac{Z_{0000} + Z_{0100} + Z_{2200} + Z_{2300}}{4} \quad 2$$

Where, H_{0000}, H_{0100}, H_{2200} to H_{2300} and Z_{0000}, Z_{0100}, Z_{2200} and Z_{2300} represent the hourly values of the H and Z components at 01:00 to 24:00 LT hours. The midnight baseline values were further subtracted from the hourly values to get the hourly departures from the midnight for same particular day, this relation is expressed as;

$$\Delta\mathrm{H} = H_t - H_b \quad 3$$

$$\Delta\mathrm{Z} = Z_t - Z_b \quad 4$$

Where t is the time in hours and ranged from 01:00 to 24:00 LT.H_t and Z_t are the hourly values of the two components H and Z for both quiet and disturbed days. The hourly departure is further corrected for non-cyclic variation for each component, a phenomenon where the difference between the value of a field at the 1st and 24th LT hour is eliminated according to Vestine (1947); Matsushita and Campbell (1967). This is achieved by making linear adjustment on the daily hourly values of the Sq using the following relation:

$$\Delta_{\mathrm{k}} = \frac{\mathrm{M_1} - \mathrm{M_{24}}}{23} \quad 5$$

where M_1, M_2 …M_{24} represent the hourly values of ΔH and ΔZ at 01:00 LT, 02:00 LT ….24:00 LT. The linear adjusted values for each hour is given as:

$$\mathrm{M_1} + 0\Delta_{\mathrm{k}},\ \mathrm{M_2} + 1\Delta_{\mathrm{k}}, \ldots\ldots\ldots\ldots\ldots\mathrm{M_{24}} + 23\Delta_{\mathrm{k}} \quad 6$$

The linearly adjusted values are expressed in the relation below:

$$\Delta H_t\,(M) = M_t + (t-1)\Delta_t \quad 7$$

$$\Delta Z_t\,(M) = M_t + (t-1)\Delta_t \quad 8$$

Hence, the corrected non-cyclic hourly departures gives the solar daily variation of H and Z components during quiet and disturbed periods. The seasonal variations are grouped into three seasons in accordance to Llyod (1861) with equinoctial season comprising of (March, April, September and October), June solstice (May, June, July and August), December solstice (November, December, January and February). Each season is deduced by taking average of all monthly mean values of each hour under a particular season for both elements during quiet and disturbed periods.

Results and Discussion

Diurnal Variation of H during Quiet Periods (SqH)

From Fig. 1a and 1b, it is readily seen that SqHexhibit day-to-day variability which is large particularly during the equinoctial months (March, April, September and October). The Figures demonstrates the presence of night-time (18:00-04:00 LT) magnitudes with peakvalue (~20 nT) around 18:00 LT in April 2011. It maintained this maximum value (~20 nT) through 2012 but shifted to February. The night-time magnitudes are observed to drop by ~15nT around 18:00LT in June 2013. This implies the night-time enhancement of SqH decreases with increasing solar activity. Besides these night-time magnitudes S_qHshow minimum pre-sunrise (05:00-07:00 LT) positives amplitudes with maximum value (~39 nT) in May 2011.

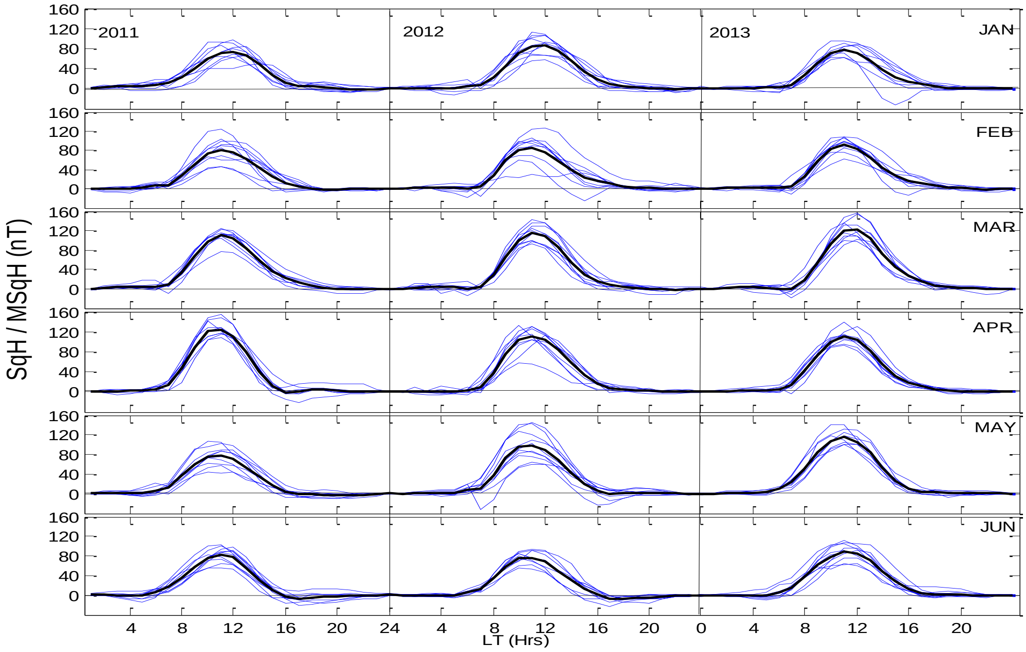

Figure. 1a Diurnal variations of S_qH during quiet days from January to June

In 2012, the magnitude had decreased to ~35 nT seen in June. With increase in solar activity, these magnitudes were observed to further drop to ~30nT as depicted in June 2013. The day-time SqH magnitudes were observed to vary in magnitudes from one quiet day to another. For example, the daytime maximum SqH amplitudes fluctuate between ~40 and 155 nT in May and April 2011 and ranged between ~45 and 160 nT in 2012 seen in November and September. In 2013, the amplitudes had not changed much it ranged between ~50 and 162nT also seen in November and September. Generally, it can be seen that SqH continue to rise steeply during the sunrise (07:00-08:00 LT) to reach peak values mostly around (10:00-12:00 LT). This feature agrees with earlier observations by research workers e.g. Onwumechili (1960); Matsushita (1969) and Rabiu*et al.,* (2007). The decrease in S_qH was rather gentle and reaches its base level mostly at sunset. In some occasions, the Sq*H* show negative depression lasting for about 2-3 hours LT particularly during the pre-sunrise and the pre-sunset hours, indication of reversed eastward equatorial electro jet currents.

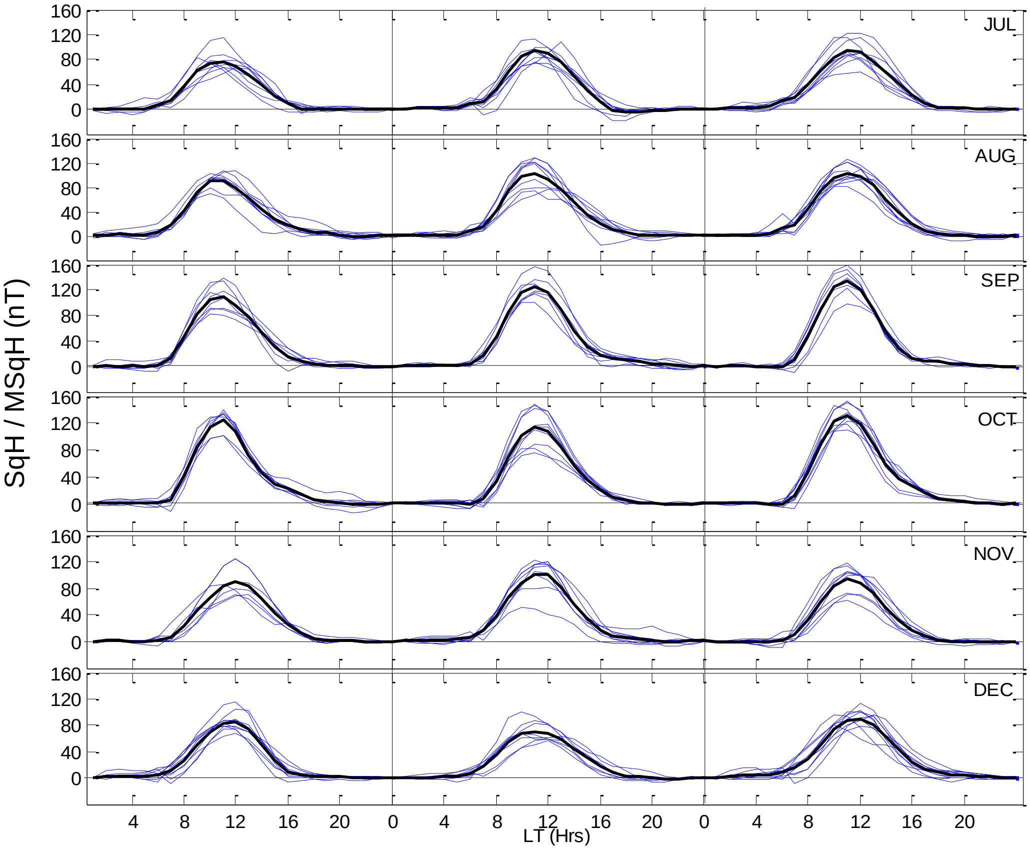

Figure. 1b similar to Figure 1a but for July to December

During CEJ events, the magnitudes of the westward current in $S_q H$ were observed to be highest (~-21 nT) around 17:00 hrs LT in June 2011. The negative amplitude increase to ~ −32 nT around 07:00hrs LT in May 2012 and slightly increase in 2013 to ~-33 nT around 15:00 hours LT seen in January. The CEJ events were observed to be more frequent during the winter months (May, June, July and August) when the variations of SqH are generally low due to reduced solar intensity solar.

Diurnal Variation of Z during Quiet Periods (SqZ)

Figures. 2 (a and b) are very much similar to fig 1a and 1b for S_qZ. The variability of S_qZ also shows the presence of night-time (18:00-04:00 LT) magnitudes that are generally low with highest value (~25 nT) seen in July 2011. The night-time magnitude is observed to decrease to ~20 nT in August 2012. Year 2013 is not exception to these night-time magnitudes with maximum value (~15 nT) recorded in July.The day-time variability of S_qZ shows highest value (~60 nT) in November 2011 and later dropped to ~59nT in March 2012. The highest day-time S_qZ magnitudes (70nT) was observed in September 2013.

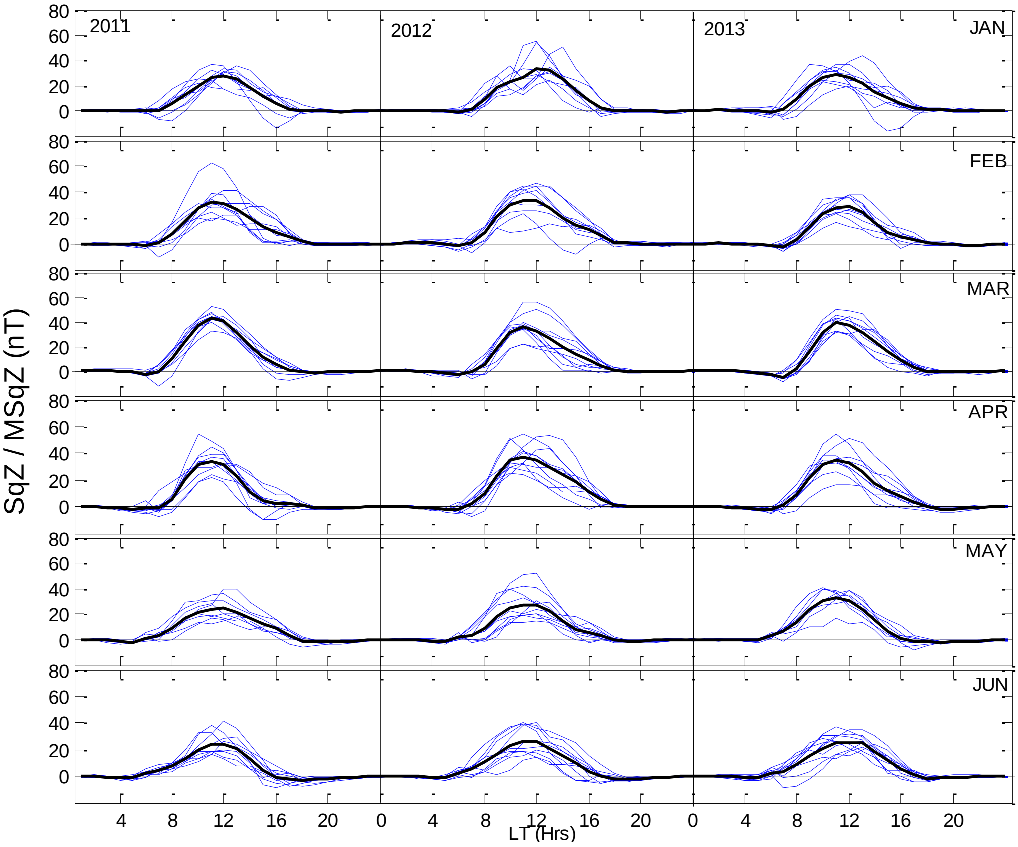

Figure. 2a Diurnal variations of S_qZ during quiet days from January to June

Generally, S_qZ shows daytime variation pattern similar to S_qH for it rises at sunrise (0:700-08:00 LT) hrs, reached peak mostly around noon (10:00-12:00 LT) and decrease afterwards.

These day-time positive magnitudes of S_qZ are in accordance to Chapman's model of a typical station on the southern edge of the magnetic dip equator. The enhanced positive variation of S_qZ are seen to continuously reduced in the months of May, June, July, August and September 2011. Similar features are also seen in May, June, July and August in 2012 and 2013 respectively. These reduced S_qZ amplitudes were observed to be in the negative range around (10:00-12:00LT) in the months of August and September 2011. The continuous reduction of daytime S_qZ magnitude is an evidence of gradual weakening of direct ionospheric sheet current due to low solar intensity and the slowly effect of induced current from the Earth surface which become stronger in August and September 2011 resulting to practical cancellation of the direct ionospheric sheet current.

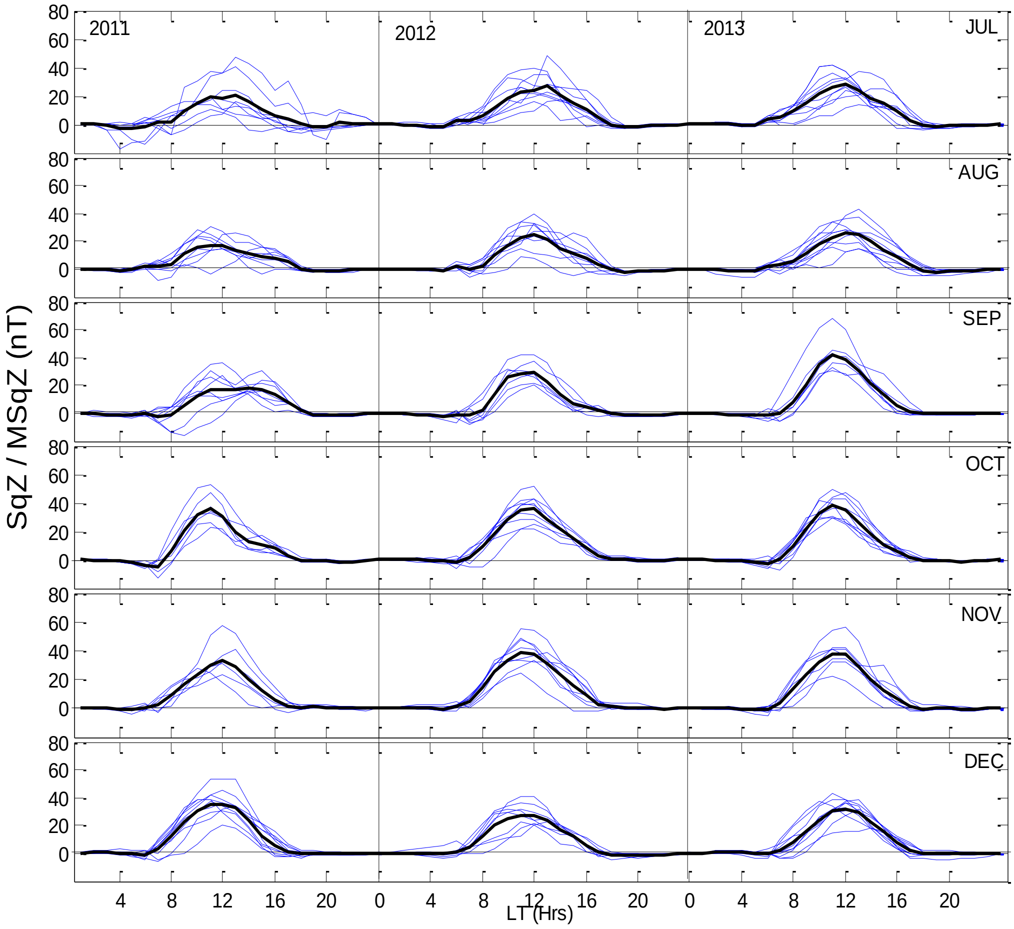

Figure. 2b similar to Figure 2a but for July to December

Similar negative amplitude of SqZ has been earlier reported by Okeke et al., (1998) and attributed it to induced current from the solid Earth surface. Hence, we infer that the solar daily variation of S_qZ over the Malaysia is not just the effect of direct ionospheric current but a combined effect of the eastward ionospheric current in the E-region of the ionosphere and the induced current from the solid Earth surface. Irrespective of the day, the variability of S_qH

are generally seen to be larger than those of S_qZ. Their greater magnitudes are direct effect of ionospheric current system.

Diurnal Variations of H during Disturbed Periods (SdH)

Figures. 3a and 3b shows the behavior of the solar disturbance (SdH). As can be observed, SdH are characterized by night-time magnitudes with highest amplitude~110 nT in September 2011 and decreased to ~90 nT in February 2012 and ~70 nT in December 2013.The SdH are observed to increase sluggishly to reach their peak values around (10:00-14:00 LT) and decreased slowly beyond the dusk period, indication of likely modification of the normal eastward current during day-time hours over the Malaysian sector.

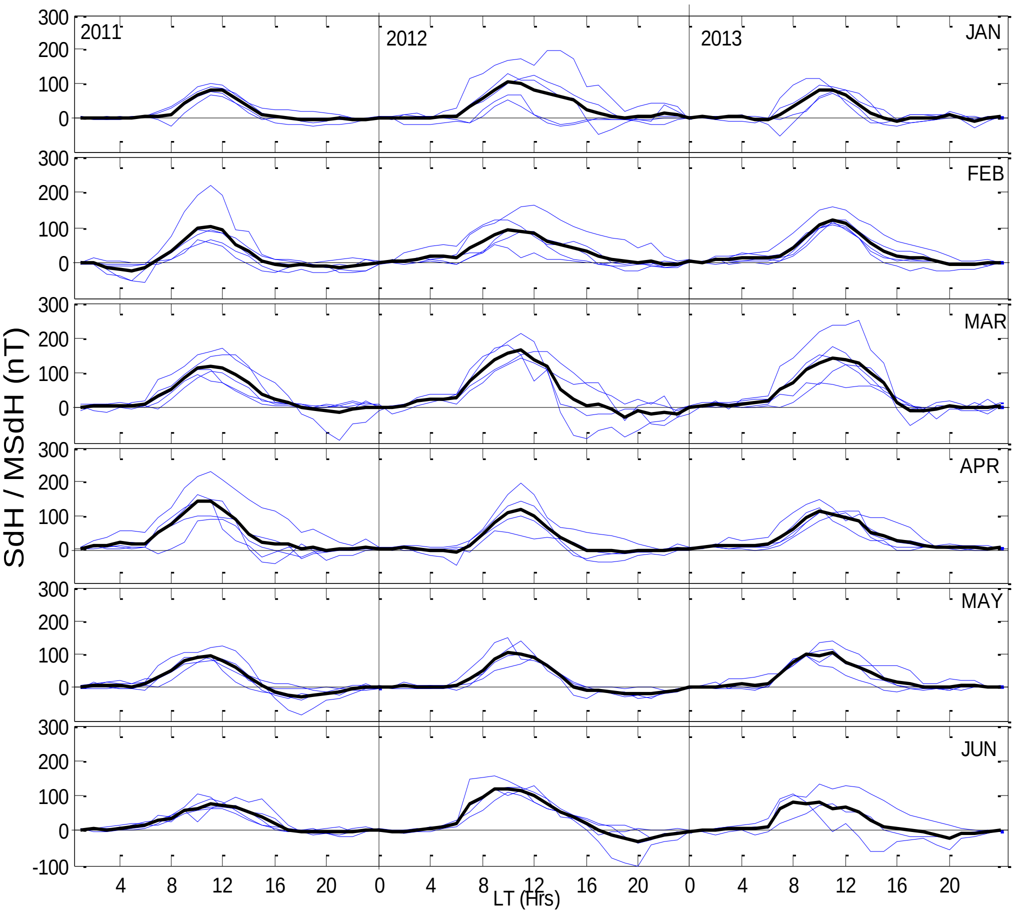

Figure. 3a Diurnal variations of S_dH during disturbed days from January to June

From fig 3a and 3b, the daytime magnitude of SdH attained highest value (259 nT) in September 2011 and dropped to 220 nT in November 2012. These amplitudes were observed to increase to 260 nT in March 2013. Some of the day-time diurnal amplitudes of SdH were observed to be very low which are more noticeable in the months of June and September 2011 with similar occurrence in January, February, March, April, September and November 2012.Year 2013 is not exception to these reduced magnitudes, seen in almost all the months' exception of February, April, July, September and November. These lower values of SdH with negative range during day-time arise from strong influence of westward current over the EEJ zone with stronger effect in June and August 2013.

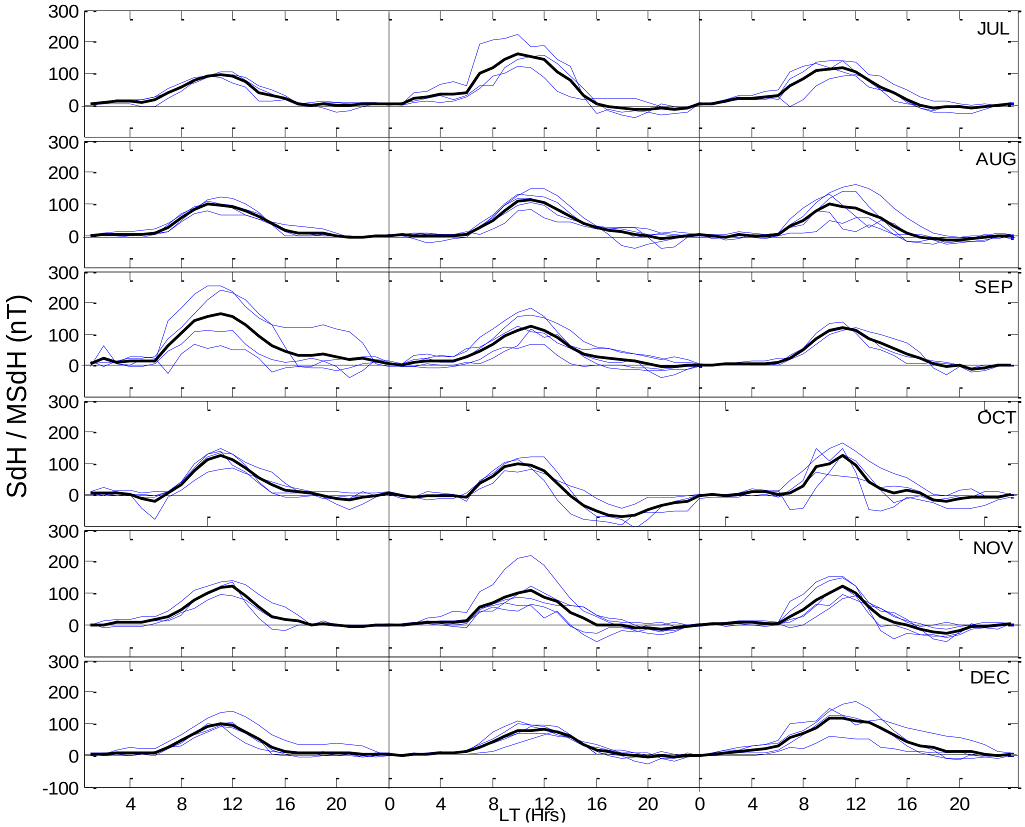

Figure. 3b similar to Figure 3a but for July to December

Figure 3a and 3b shows prominent westward current during the pre-sunrise and (05:00-07:00 LT) and pre-sunset to nighttime (14:00-04:00 LT) hours. The magnitudes of the westward current of SdH reached highest value ~-100 nT around 21:00 LT in March 2011 and decreased to ~-90 nT in June 2012. In 2013, the amplitude had decreased to ~-80 nT still in June. These negative amplitudes of S_dH are consequence of stronger magnetospheric current effect. Generally, the day-time SqH and SqZ magnitudes were observed to be greater than their night-time magnitudes in all the years.

Diurnal Variation Z during Disturbed period (SdZ)

In Figure. 4 (a and b), the S_dZ also shows night-time variations with lower magnitudes compared to corresponding S_qZ amplitudes. The maximum amplitude (15 nT) is observed in September 2011 which decrease to ~10 nT seen in March 2012 and January 2013. The S_dZ, magnitude reached ~60 nTin February 2011 and dropped to ~59 nT in April 2012 with a sharp increase to about 62 nT in January 2013. During disturbed period, S_dZ shows weak amplitudes in May, June, August and September across all the years. These weaker amplitudes were further observed to be negative particularly in August 2011, June and July 2012 with similar occurrence in July 2013. We infer that these weak amplitudes are direct consequences of induced current from the solid Earth in combination with the disturbed external currents.

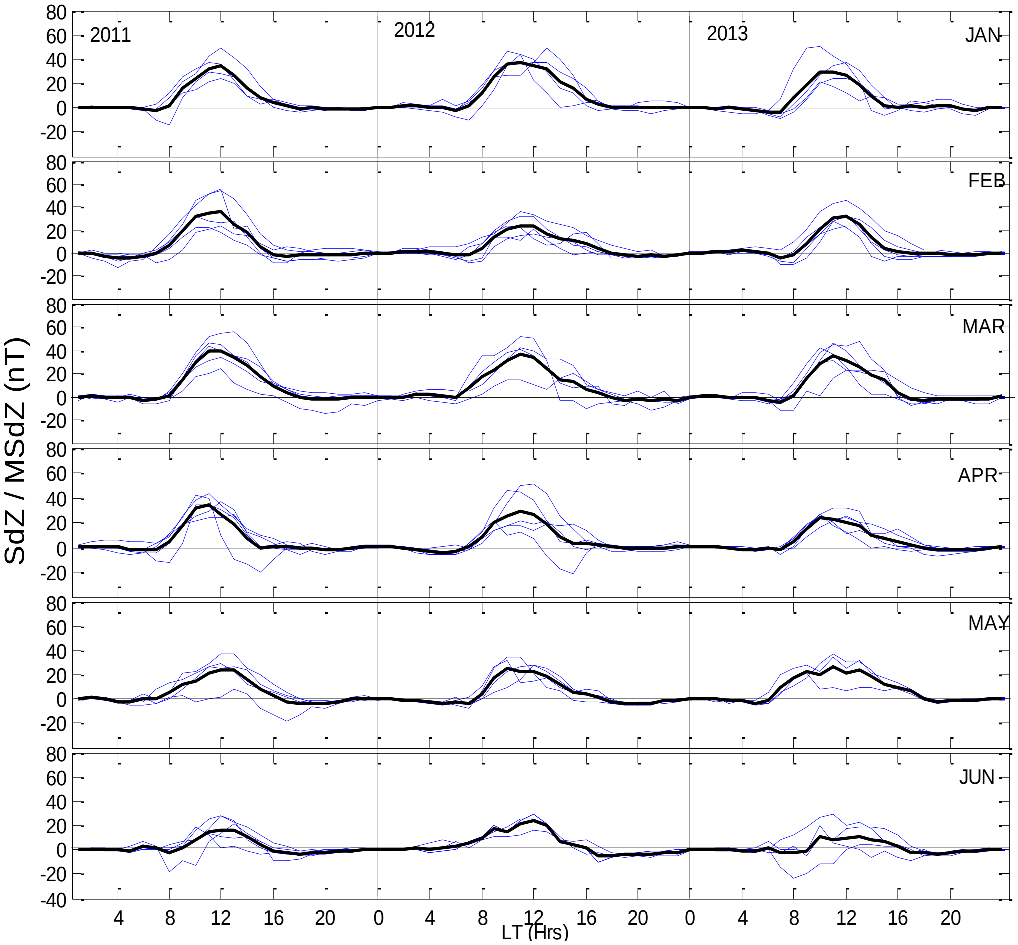

Figure. 4a Diurnal variations of SdZ during disturbed days from January to June

Monthly Diurnal Variations H and Z Components during Quiet and Disturbed Periods

From Fig 1a and 1b, the monthly diurnal variations of H during quiet (MSqH) and disturbed (MSdH) that are represented by thick black curve shows a smooth appearance that start to build up during the sunrise (05:00-07:00LT) with peak value mostly around noon (11:00-12:00 LT) hours and decline afterwards. The range in day-time MSqH magnitudes were observed to vary from one month to another. For example, the range in MSqH day-time Magnitudes in 2011 were found to be between ~75 and 125 nT seen in July and October. In 2012, the amplitudes had increased to a range between ~70 and 125 nT in December and

September. In 2013, the amplitudes oscillate between ~78 and 135 nT in January and October indication of increase in daytime MSqH amplitudes with increasing solar activity.

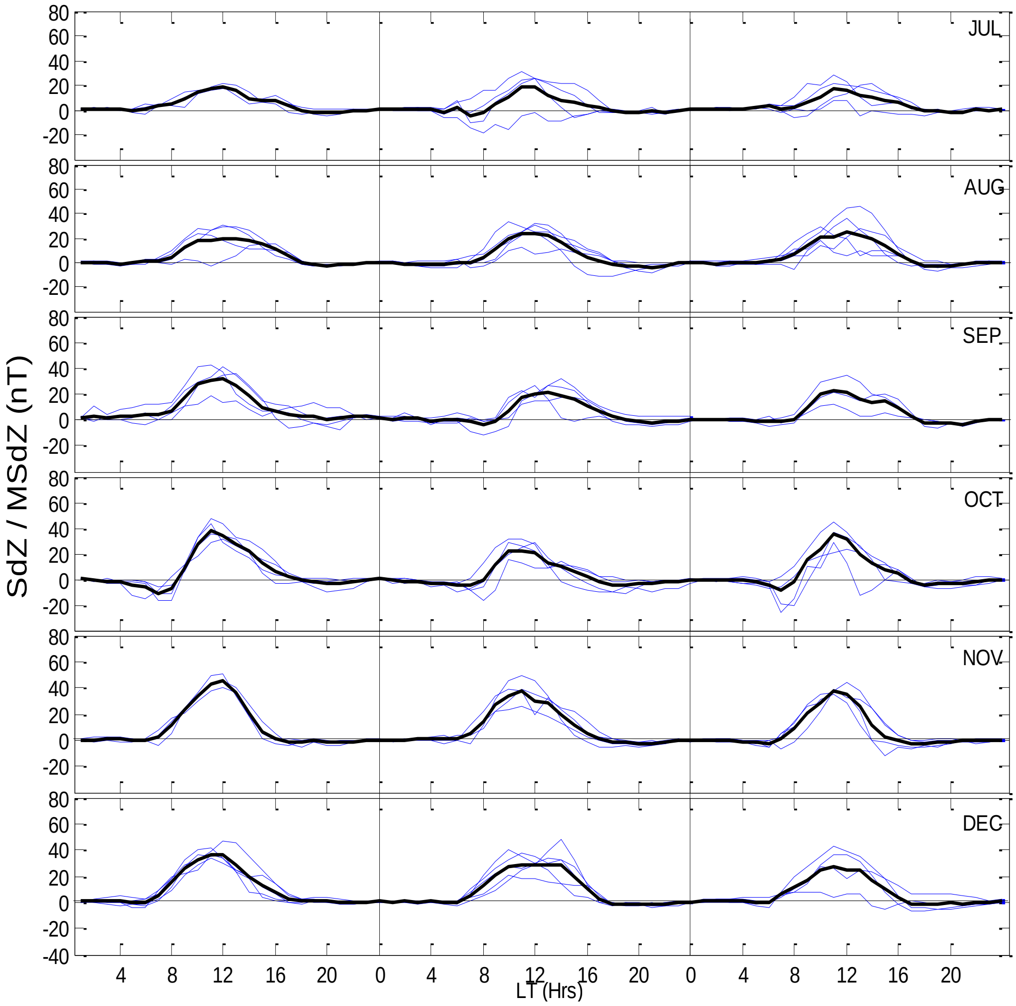

Figure 4b similar to Figure 4a but for July to December

It is obvious from Fig. 2a and 2b, that the MSqZ denoted by thick black curve, shows positive variation that start to build-up around (05:00-07:00 LT) hours. Exceptions to these early ionizations are the months of July, August and September seen at 08:00hrs LT. These months exhibit MSqZ variations with broad phase which extend towards the night-time periods. Similar features are also observed in May, June, July and August in 2012 and 2013 respectively. This characteristic is not common and may be due to combine effect of induced current from the earth surface and weak eastward current caused by weaker thermal heating of the upper atmosphere around these periods. The daytime MSqZ magnitudes fluctuate between the range ~17 and 44 nT visible in August and March 2011. It oscillates between ~25 and 39 nT seen in November and December 2012. It stayed on this minimum range through 2013 but shifted to July while it maximum value (42 nT) is recorded in September. In Fig3 (a and b), MS_dH amplitudes ranged between ~76 and 166 nT in June and September 2011 and further fluctuate in the range between 81 and 164 nT seen in December and March 2012. In 2013, the amplitudes oscillate between ~81 and 145 nT in June and March. The salient feature to note here is the linear decrease in the maximum range of MS_dH with solar activity, indication of slowly build-up of westward current over the equatorial region. The day-time MS_dH variability were observed to reach their peak values mostly around (10:00-11:00 LT) in 2011. These peak shifted to around (12:00-14:00 LT) hours in 2012 and 2013 suggesting changes in the variation of the electric field during disturbed period. From Fig 4a and 4b, MS_dZ amplitudes ranged between ~17 and 45 nT in June and November 2011. In 2012, the amplitudes are seen in the range between ~19 and 38 nT in July and November and decreases in 2013 to a range between ~11 and 37 nT obvious in June and November. They show maximum amplitudes mostly around (11:00-14:00 LT) hours. Our results show that MS_dH and MS_dZ exhibit weak amplitudes values in the winter months (May. June, July and August).Generally, the variability of MS_qH and MS_dH for any of the months through the years is greater than their corresponding MS_qZ and MS_dZ Variations. Their great magnitudes are attributed to stronger ionospheric current effect to which H-component is more susceptible.

Seasonal variations of SqH and SdH

Figure. 5 shows that the day-to-day variability of SqH and SdH exhibit seasonal variations for both quiet and disturbed conditions. The black, red and blue curve represent December solstice, equinox season and June solstice during quiet periods while their corresponding dash line with asterisks depict their disturbed variations. It is readily seen that seasonal variations shows systematic increase for both elements (H and Z). For example, regardless of the year, SSqH increased linearly from ~80, 80 and 120 nT In June solstice, December solstice and equinox season in 2011 to peak amplitudes values ~90, 100 and 130 nT seen in 2013, indication of possible influence of solar activity on the seasonal variations. Similar equinoctial maxima have earlier been reported by Chapman and Raja Rao (1994), Chandra et al., (1971), Campbell (1982), Rastogi et al., (1994), Bolaji et al., (2012). Thus greater SSqH magnitude at the equinoctial season may likely be due to greater daytime E-region conductivity with minimal loss rate. Similar behavior is observed in SSqZ with peak amplitudes~20, 32 and 33 nT in June solstice, December solstice and equinoctial season in the year 2011. These magnitudes were observed to increase to ~28, 34 and 37 nT in 2013.

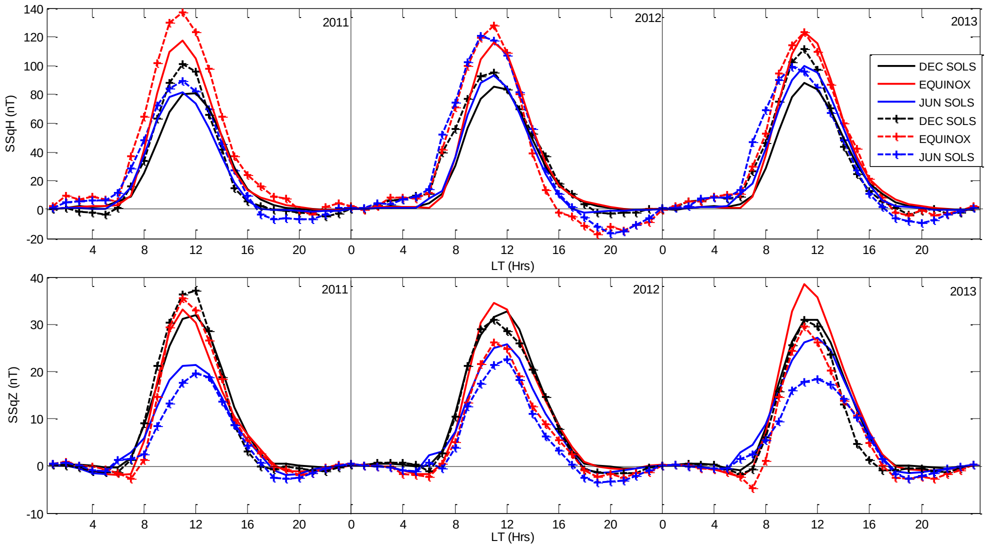

Figure 5 seasonal variations of SqH,SdH,SqZ and SdZ

Our seasonal variations show lower values in solstices and higher values in equinoctial season resulting to semi-annual variations pattern. Stening (1994) reported semi-annual variation in equatorial electro jet to be due to a decrease at the solstices rather than an increase at the equinoxes. Bolaji*et al.*, (2013) suggested variability of equatorial electro jet current (EEJ) on the horizontal component of the Earth magnetic field could be responsible for the observed semi-annual variation of SqH. During disturbed period, SSdH does not show any linear increment with increase in solar activity but rather a decrease was observed particularly in the equinox season from 138 nT observed in 2011 to 133 and 128 nT in 2012 and 2013 respectively. This linear decrease in SS_dH with solar activity at the equinoctial season is evidence of weakening of disturbance effect with increasing solar activity. Similar decrease is also seen in SSdZ during December solstice from 38 nT in 2011 to 29 and 30 nT in 2012 and 2013. The June solstice for both SSdH and SSdZ shows peaks values that are lesser than those of equinox and December solstice. The overall seasonal variation shows peak values around (11:00-12:00 LT) hours, with greater variation during magnetically disturbed period than their counterpart quiet periods. Their greater magnitudes may likely be that extra energy is imputed in the eastward direction mainly during daytime.

Yearly Mean Solar Daily Variations

Figure 6 shows the average yearly mean daily variations for the two elements (H and Z) for both quiet and disturbed conditions. The annual mean (AS_qH) of S_qH is represented by red dash line and their disturbed variation (AS_dH) is denoted by red dash line with asterisks. Similarly, the black curve represent the annual mean solar variation of S_qZ (AS_qZ) while their disturbed variation (AS_dZ) are represented by black dash line with asterisks. For both conditions, the increase in AS_qH and AS_dH occurred before 05:00 hrs LT with pronounced magnitudes in AS_dH particularly in the year 2012 and 2013. These magnitudes (few nT) in AS_dH were observed to subside with incoming solar radiation around 05:00-06:00 LT and further increase immediately during the sunrise (06:00-07:00 LT) period, indication of different mechanism responsible for their source. The pronounced magnitudes in AS_dH before pre-sunrise are evidence of current effect outside ionospheric influence in addition to world solar quiet (WS_q) that flows eastward at night-time in the absence of equatorial electrojet current.

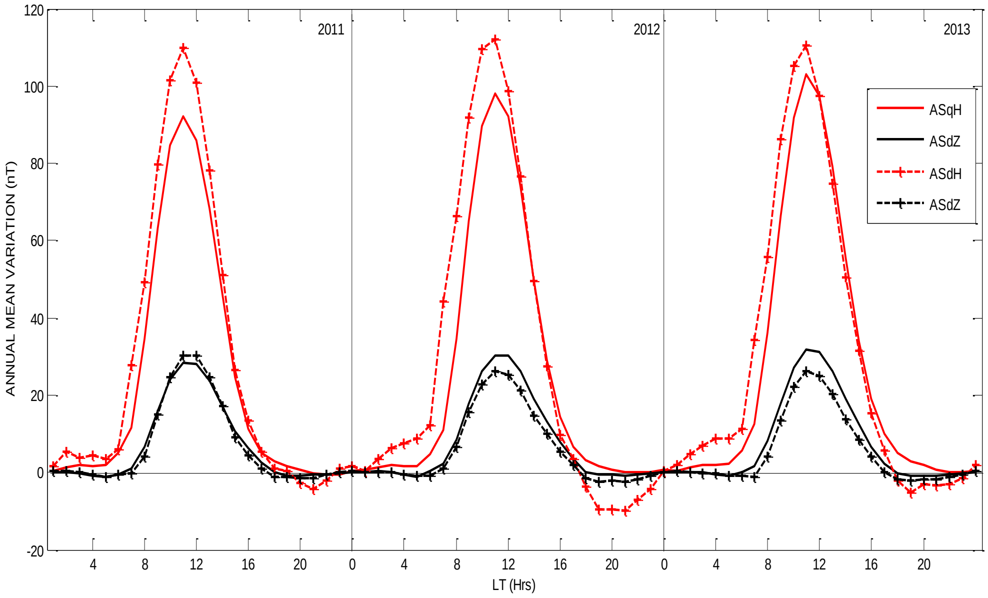

Figure 6 Yearly average solar daily variations of Sq and Sd

The variations of AS_qH were observed to increase linearly with solar activity to reach peak values 92, 98 and 103 nT in 2011, 2012 and 2013. AS_dH shows similar increment with peak values 110,115 and 117 nT seen in 2011, 2012 and 2013 respectively. The variability of AS_qH and AS_dH were observed to reach their peak values at 11:00 hrs LT. Another feature to note here is that the annual mean solar variation during disturbed period (AS_dH) exhibit significantly larger values compared with the corresponding values for quiet periods over the Malaysian ionosphere. Our findings are in contrast to the Indian and American observation by Rastogi (1998) that found greater magnitudes of annual mean solar daily variation during quiet days to disturbed period. The increase in AS_dH in our result may likely be due to modification of the normal eastward current or arises from the increase in strength and width of the equatorial electro jet current during magnetically disturbed period. Also from fig.5, the AS_qZ shows variation pattern similar to AS_qH, it steeply increase to peak amplitude values 28, 30 and 32 nT in 2011, 2012 and 2013. During disturbed period, AS_dZ attained maximum value 30, 26 and 27 nT in 2011, 2012 and 2013. This non-linear increment in AS_dZ might likely result from the combined effect of the disturbed ionospheric current in the E-region of the ionosphere and induced current from the Earth surface. Beside these maxima, the AS_dH are characterized by depression that fluctuate in the range between -1 and -5 nT in 2011 and 2012 around 18:00 hrs LT indication of westward current around these periods. The vertical component readily responds to these westward current with lesser magnitudes compared to the ones in AS_dH.

Conclusions

This paper presents the characteristics of both solar quiet and disturbed variations of the horizontal and vertical components of the Earth magnetic fields. The result reveals that the daytime SqH and SdH and their monthly mean (MSqH and MSdH) linearly increase with increasing solar activity but latter consistent show irregular variation pattern. The SqH and SqZ demonstrate the presence of night-time to pre-sunrise magnitudes that decreases with solar activity. The sluggish increase in S_dH at sunrise to peak values mostly around (10:00-14:00 LT) and the gradual decrease even after dusk are evidences of likely modification of the normal eastward current during perturbed conditions over the Malaysian sector.

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