Space Research Journal

ISSN 1819-3382

Academic Journals Inc.

www.academicjournals.com

Space Research Journal 4 (1): 12-22, 2011
ISSN 1819-3382 / DOI: 10.3923/srj.2011.12.22

Inter-hemispheric Trans-equatorial Field-aligned Currents Deduced from MAGDAS at Equatorial Zone

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ABSTRACT

This study report for the first time the existence of Inter-Hemispheric Field-Aligned Currents (IHFACs) mainly at the dusk sector and Trans-Equatorial Field-Aligned Currents (TEFACs) deduced from S_q(D) within the equatorial region of Africa using Magnetic Data Acquisition System (MAGDAS). One-minute data set of the magnetic field variation of the three components H, D and Z was examined and analyzed using MATLAB[R] program by deducing the baseline value at midnight-hours which reduces disturbances from local effects to minimal level, the baseline value is further deducted from each magnetic field component values at each hour and the result is approximately equal to ionospheric currents S_q. S_q(D) exhibit distinct features of magnetic field variations. S_q(H) and S_q(Z) were compatible in December where both variations rises at about the sunrise 0600 h LT, peaks at about local noon and a gentle fall at about sunset 1800 h LT. This distinct features of magnetic field variation in D component was attributed to the Inter-Hemispheric Field-Aligned Current System (IHFACs) which was responsible for the diurnal S_q(D) and mean monthly variation of S_q(D) and the Trans-Equatorial Field-Aligned Current System (TEFACs) was responsible for seasonal S_q(D). IHFACs confirmed magnitudes and variations of S_q(D) during the dusk sector by MAGDAS. These IHFACs were found to flow from the summer hemisphere to the winter hemisphere in the dawn sector and from the winter hemisphere to the summer hemisphere in the noon and the dusk sectors in the months of August and October. IHFACs current intensity in the dusk sector is strongest in the month of December. TEFACs have tendencies to flip their direction at Equinox because its magnitude is maximum and have minimum magnitudes at June and December solstices. The least magnitude of the current intensity of the TEFACs is accounted for at December solstice.

Key words: MAGDAS, inter-hemispheric, trans-equatorial, field-aligned current, ionospheric current S_q

INTRODUCTION

The objectives of this study are to estimate the ionospheric current S_q using magnetic field intensity data of the three components H, D and Z, examine existence and account for the inter-hemispheric and trans-equatorial field-aligned currents system (hereafter reffered to as IHFACs and TEFACs respectively) from S_q(D).

The records of magnetic field intensity measurements taken in the year 2008 from the archive of MAGDAS installed (located) at University of Ilorin, Nigeria, on geographical coordinates (8.47°N, 4.68°E) and angle of dip (4.1°S) in 2006 by Space Environment Research Centre (SERC) of Kyushu University (KU), Japan was inconsistent due to electricity fluctuation. Only the months of August, October and December data in the year 2008 could be retrieved.

Yumoto and MAGDAS group (2007) introduced MAGDAS instrument as the project of SERC, KU, Japan in which the data can be used to monitor global electromagnetic and plasma environment change in geospace and then to bring about a better understanding of the complex and compound Sun-Earth system.

For many years it was assumed that ionospheric current flow only horizontally, which means that current system derived from ground-based magnetograms were really only equivalent current systems since the possibility of vertical current had been excluded.

The idea about field-aligned currents was first put forward by Birkeland-Alfven's (1908), this idea was dormant for many years due to lack of evidence. The field-aligned currents Birkeland originally depicted were not the present-day Birkeland currents inside the magnetosphere, he described then that they were directly from the Sun toward the Earth and back. At the time of Birkeland, the existence of the ionosphere and the magnetosphere was still unknown and Birkeland thought of a stream of charged particles coming directly from the Sun to the Earth's atmosphere in high latitudes. It began to return to limelight on theoretical basis in the 1960s. Several more years passed before solid evidence start emerging through the studies of the ionosphere. Birkeland current idea was first supported by Alfven (1939) when he introduced a new theory of magnetic storms.

Later, Cummings and Dessler (1967) named the field-aligned currents flowing into and out of the high-latitude ionosphere as Birkeland currents to commemorate his early work of introducing such currents to explain the polar elementary storms and since then Birkeland currents became very popular in space physics.

The convinced observations came from magnetic measurement on satellites 1963 38C by Zmuda *et al.* (1966), although he attributed the signatures of field-aligned currents to hydromagnetic waves. ISIS2, TRIAD and MAGSAT satellites in the early 1970s contributed greatly to reveal the important features of field-aligned currents as the regions of incoming and outgoing currents, their dependence on geomagnetic activity and solar wind conditions and so forth, including the complicated field-aligned current patterns at high latitudes in the evening sector. The field-aligned currents in the magnetosphere became indispensable in the discussion of the magnetosphere-ionosphere coupling. After these observations, lot of researchers has worked extensively within the low and mid latitude using many satellites and few ground-based magnetometers.

Fukushima (1979) theorem combined and compared the Alfven and Chapman ideas about equivalence of different current systems as detected by satellites in the space and magnetometer on the ground. It revealed that vertical current cannot be detected on the ground but could be detected in space.

IHFACs at mid and low latitudes are believed to be caused by inter-hemispheric imbalance of the horizontal Sq current system, Van Sabben (1966, 1969 and 1970).

Maeda (1974) and Fukushima (1979, 1993) theoretically predicted IHFACs existence by calculating the ionospheric electric potential in both hemispheres and supported the Van Sabben's idea.

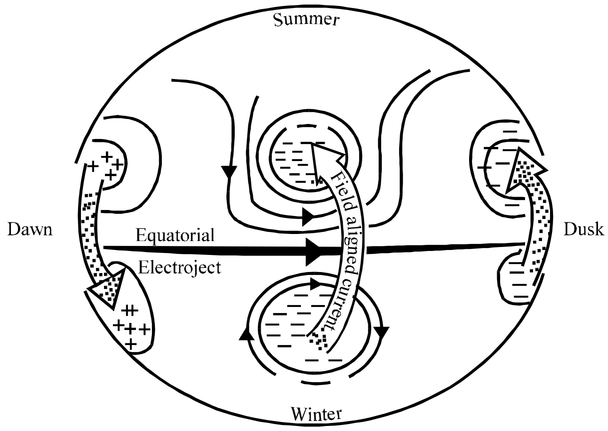

Fig. 1: A model of inter-hemispheric trans-equatorial field-aligned currents in the magnetosphere at middle and low latitudes

Schematic diagram for the ionospheric and field-aligned currents in the sunlit hemisphere is shown in Fig. 1. It showed the S_q(D) currents flowing from the winter hemisphere to the summer hemisphere in the noon and the dusk sectors and in opposite direction in the dawn sector. It also depicts the eastward (positive) magnetic field variation in the dawn sector and the Westward (negative) magnetic field variation in the noon and dusk sectors in Northern summer.

Later studies on the S_q current system using the ground-based geomagnetic field data supported the existence of IHFACs (Takeda, 1990; Fukushima, 1994; Stening, 1989).

From the first International Geophysical Year (IGY) program and for the first time, Forbush and Casaverde (1961) reported IHFACs over equatorial region of Huancayo that the North-South spatial depended on the ground magnetic effect of the equatorial electrojet. From second IGY program, Gettemy (1962) also estimated the daily variation at Koror on the Western Pacific Island on quiet days for the three components of the geomagnetic field.

Olsen (1997) showed the upward and downward ionospheric currents on the dawn-dusk meridian plane using the Magsat data and suggested that these ionospheric currents are identical to IHFACs in the dawn and dusk sectors.

Takeda (2002) believed that the equivalent current of summer hemisphere invades winter hemisphere and that the equivalent current is distorted compared to the horizontal Sq current. The equivalent current contains the horizontal Sq current and the IHFACs. The invasion of the equivalent current in summer hemisphere to winter hemisphere is caused by the IHFACs. The invasion of the equivalent current is clear in the morning sector, which indicates the existence of the IHFACs in the dawn sector. The distortion of the equivalent current can be explained by the IHFACs in the dawn sector, around the noon and in the dusk sector.

Yamashita and Iyemori (2002) reported and proved for the first time a clearer evidence of the existence of IHFACs, its seasonal dependence and local time distribution using Ørsted satelhte and ground-based geomagnetic field observations at seventeen mid and low latitudes stations.

The earth and its atmosphere receives from the Sun a constant amount of energy at every instant throughout the year, regardless of the season (neglecting the influence from a small annual fluctuation in the Sun-Earth distance) but the geomagnetic S_q(D) field shows its maximum magnitude in the equinoctial season at most observatories at mid and low latitudes on the Earth.

Solar wind generated at low latitude magnetic variations are predominantly related to IMF B_Z, the North-South component of the Interplanetary Magnetic Field (IMF), Lesur *et al.* (2005). Lesur *et al.* (2005) found that the east-west component of the magnetic disturbance displayed variations following closely the interplanetary sector structure, a direct penetration of the IMF were tentatively suggested as a possible cause. Alternatively, low latitude interhemispherical FACs were also suggested. Vennnerstrom *et al.* (2007) investigated this effect of IMF B_y using Oersted satellite magnetic data at mid- and low latitudes for a longer time-period and included all local times. In addition, they compared with statistical models of high-latitude FAC patterns and concluded that the IMF B_y effect is most likely due to a long-distance contribution from the high-latitude FACs.

Trans-Equatorial Field-Aligned Currents system (TEFACs) flow in the magnetosphere to cancel or at least reduce the electric potential difference at conjugate-pair stations in the northern and southern hemispheres and the Pedersen currents in the ionosphere connected to these field-aligned currents produce the Joule heat so as to lose the electromagnetic energy stored in the ionosphere-magnetosphere region. Since the north-south difference of electric potentials at conjugate-pair stations is expected to be minimum in the Equinoctial season, the electromagnetic energy stored in the space around the Earth will be greatest in the Equinoctial season because its loss through the Joule heating will be minimum at the Equinox (Fukushima, 1994). This possibly explains the reason for the Equinox maximum of the geomagnetic S_q(D) field magnitudes at most observatories at low latitudes.

Based on the achievements of Fukushima (1994), Olsen (1997), Lesur *et al.* (2005) and Yamashita and Iyemori (2002) on IHFACs and Yumoto and MAGDAS group (2007) on space weather analysis using MAGDAS instrument, this study report for the first time the existence of IHFACs and TEFACs within the equatorial region of Africa using MAGDAS data.

MATERIALS AND METHODS

Magnetic Data Acquisition System (MAGDAS) data set in the year 2008 of the University of Ilorin, Nigeria, Rabiu *et al.* (2009) an equatorial electrojet belt, Rabiu (2006) on geographical coordinate (8.47°N, 4.68°E) was analyzed. The location where the research was conducted is shown in Fig. 2.

Solar daily variation: The data set investigated in this study is 1 min values of the three geomagnetic elements: horizontal component H, declination component D and vertical component Z recorded at the geomagnetic observatory within University of Ilorin, Nigeria for the months: August, October and December in the year 2008. However, the data for all other months in 2008 were missing. These 1 min data were converted to hourly values.

Average magnitude ΔH, ΔD and ΔZ components over five international quiet days for each month in each 1h local time bin was estimated. The baseline of the ΔH, ΔD and ΔZ components in each month at each station was defined as the average value of H, D and Z near local midnight (i.e., between 2400 h LT and 0100 h LT). ΔH, ΔD and ΔZ hourly departures is the residual after subtracting the baseline from the 5-quiet days average. The hourly departure is further corrected for non-cyclic variation on each component, a phenomenon in which the value at 0100 h LT is not different from the value at 2400 h LT, after Vestine (1947) and Rabiu (2000).

These hourly departure corrected values gives the solar daily variation in H, D and Z. S_q(H) denote the solar quiet daily variation in H, S_q(D) denote the solar quiet daily variation in D and S_q(Z) denote the solar daily variation in Z.

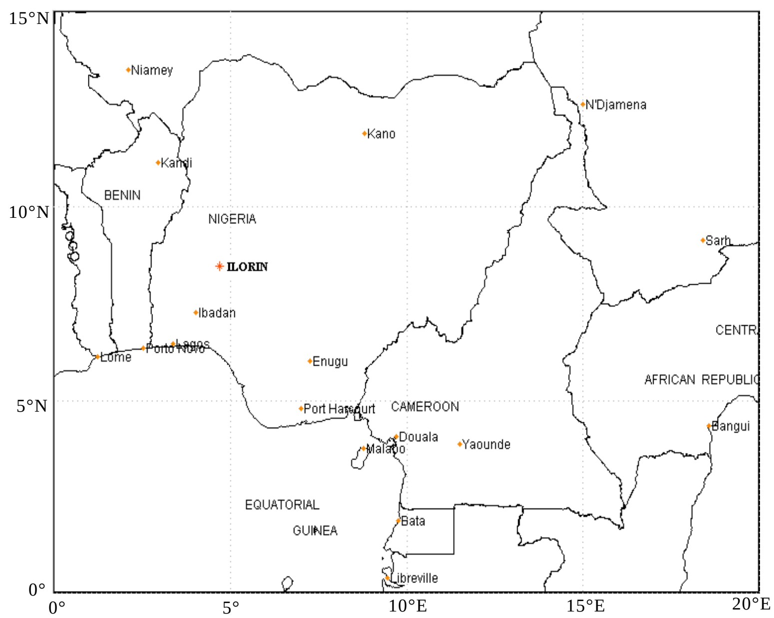

Fig. 2: Map of Nigeria showing the geographical latitude and longitude of Ilorin

International quiet days mean hourly values: The mean hourly values from a selected group of days from a month are denoted by S_qH_1, S_qH_2, S_qH_3, S_qH_4 and S_qH_5 for H element, S_qD_1, S_qD_2, S_qD_3, S_qD_4 and S_qD_5 for D element and S_qZ_1, S_qZ_2, S_qZ_3, S_qZ_4 and S_qZ_5 for Z element. These selected groups of days are the five international quietest days of the months obtained from the website: http://www.ga.gov.au/ oracle/geomag/iqd_form.jsp.

Mean monthly hourly values of solar daily variation:

- **MQH:** Mean monthly hourly values of solar quiet variation in H
- **MQD:** Mean monthly hourly values of solar quiet variations in D
- **MQZ:** Mean monthly hourly values of solar quiet variation in Z

These were estimated by finding the mean of the hourly values of solar quiet variations in horizontal intensity, declination intensity and in vertical intensity for each set of the five international quiet days of each month.

These S_q in H, D and Z, selected mean hourly values of solar quiet variations and the MQH, MQD and MQZ mean monthly hourly values of solar quiet variations were mass-plotted together against Local Time (LT) in Fig. 3-5. These examine their variations in the month of August, October and December.

The abnormal behavior of the MQD from the signatures compatibilities of MQH and MQZ intensify further effort to clearly show its diurnal and seasonal variations behaviour separately for each month of August, October and December. Diurnal MQD estimated for each month is plotted against Local Time (LT) in Fig. 6a-c. The plots reveal current intensity of IHFACs in the dusk sector (1700 h LT-1900 h LT) with clearer magnitude variations.

Seasonal variation of MQD: Following Lloyd's seasons pattern Eleman (1973), the months in the year are classified into three seasons; December Solstice or D-Season (January, February, November, December), Equinox or E-Season (March, April, September, October) and June Solstice or J-Season (May, June, July, August).

Since, each month under investigation in this study falls within the Lloyd's seasonal pattern, each month shall represent each season. That is, month of October represent E-Season, month of August represent J-Season and month of December represent D-season. Seasonal variation of MQD was estimated by finding the average of the mean monthly hourly values of solar quiet variation under a particular season. Figure 6d illustrates the seasonal variation of MQD.

RESULTS AND DISCUSSION

Diurnal variation: Figure 3-5 depict that diurnal variations exist in the entire three components on quiet days for the month of August, October and December.

There exist very similar S_q signatures in all the mean hourly values of the solar daily variation of selected five international quiet days for all the months under investigation in both H and Z components while S_q signature in D component is not in conformity with them.

S_q in H and Z components agreed with Onwumechili (1960) and Matsushita (1969) results on solar daily variation which rises at about the sunrise 0600 h LT, peaks at about local noon and a gentle fall at about sunset 1800 h LT. They attributed these to variability of the ionospheric processes and physical structures such as conductivity and winds structures. Onwumechili and Ezema (1977) also supported this result and concluded that it is explicable in terms of solar effects on atmospheric dynamo theory.

Figure 3-5 clearly showed that the magnitudes of S_q in H at any hour of the day are greater than those of the S_q in D and Z. This may be attributed to the fact that the equatorial region is in horizontal magnetic field plane, such that there are tendencies for higher magnitude of solar intensity.

The daytime (0700 h LT-1700 h LT) magnitudes are greater than the nighttime (1800 h LT-0600 h LT through 2400 h LT) magnitudes for all the months in the two elements H and Z.

This night-time variation was supported by Campbell (1973), it was noticed in S_q using geomagnetic intensity in the three elements, even when used only 37 of the quietest days during minimum solar activity in the year 1965, the variation still persisted at midnight Campbell (1979). Hence, ionospheric currents do flow at night outside the aurora and polar regions. Rabiu (1996) results is also in consistent with our result apart from Campbell (1973, 1979) by deducing a consistent night-time variation in horizontal magnetic field component at mid latitudes and attributed same to distant magnetospheric sources after Matveyenkov (1983). The variability of the nighttime field may thus be as a result of the variability of the night-time distant currents.

IHFACs on local time dependence: Most results discussed regarding S_q variations are applicable to MQH and MQZ but not to MQD. The signatures of diurnal variation of MQD in the month of August, October and December (Fig. 6a-c) was investigated and revealed the existence of IHFACs on local time dependence. Chapman and Ferraro (1931) investigated IHFACs from previous studies and concluded that the declination change is more westward (eastward) in the summer evening (dawn) and in the winter dawn (evening) in the northern hemisphere and in the summer dawn (evening) and in the winter evening (dawn) in the southern hemisphere.

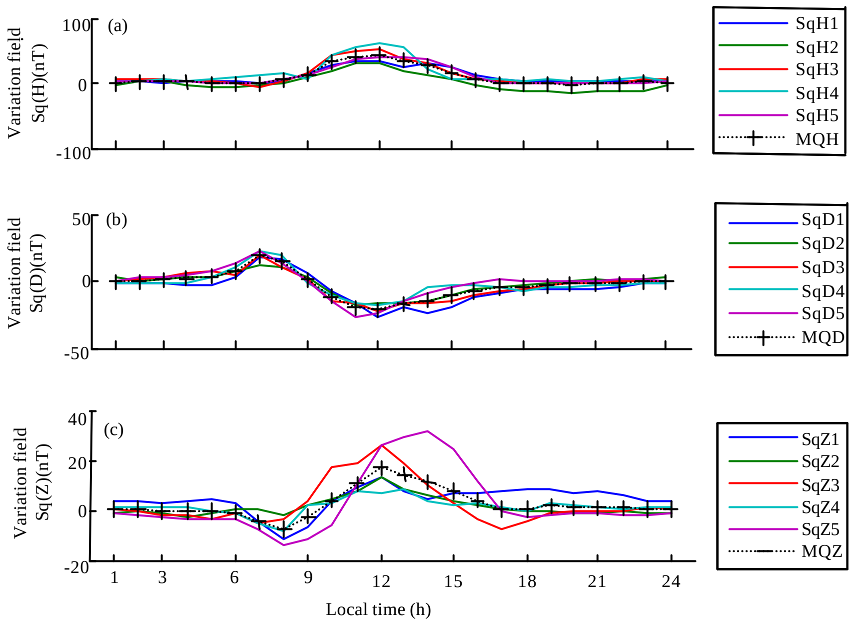

Fig. 3: (a) Diurnal variation of S_qH for August, (b) Diurnal variation of S_qD for August and (c) Diurnal variation of S_qZ for August

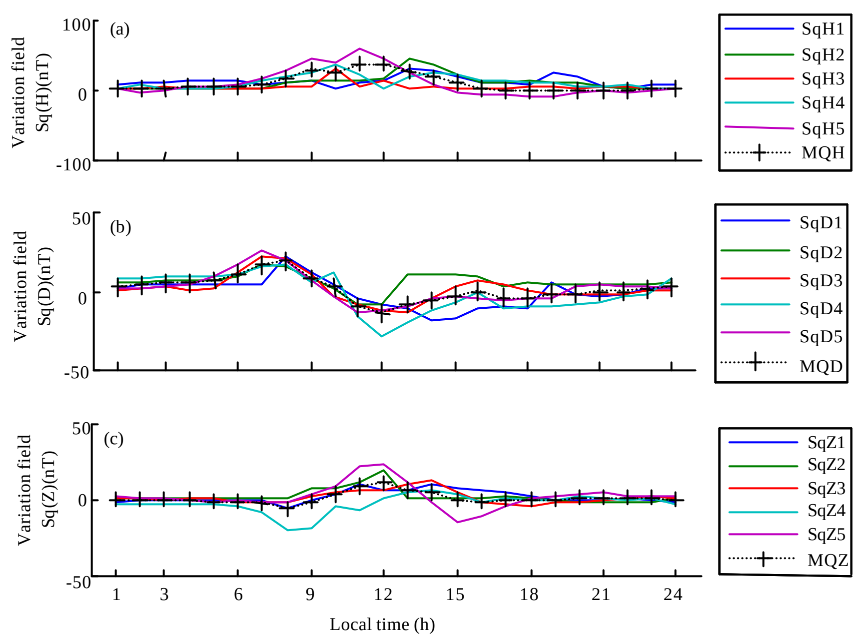

Fig. 4: (a) Diurnal variation of S_qH for October, (b) Diurnal variation of S_qD for October and (c) Diurnal variation of S_qZ for October

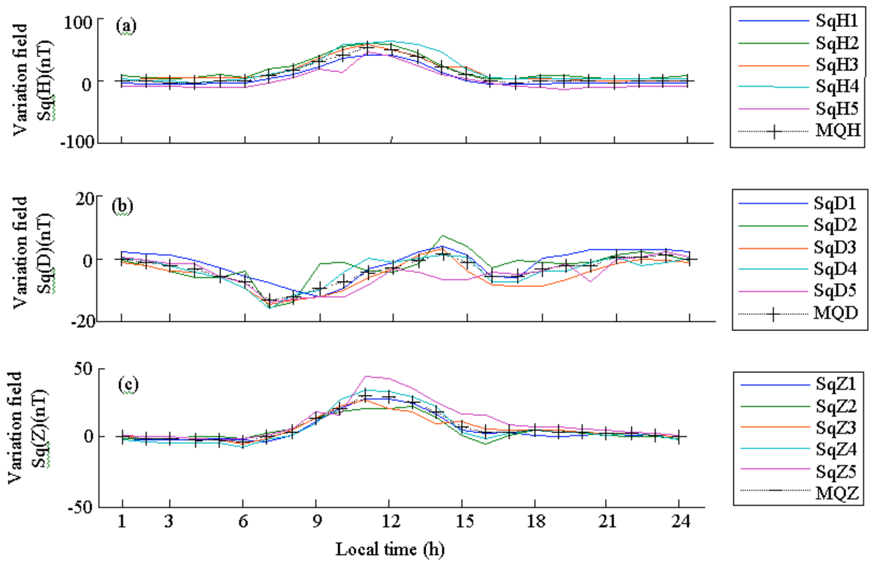

Fig. 5: (a) Diurnal variation of S_qH for December, (b) Diurnal variation of S_qD for December and (c) Diurnal variation of S_qZ for December

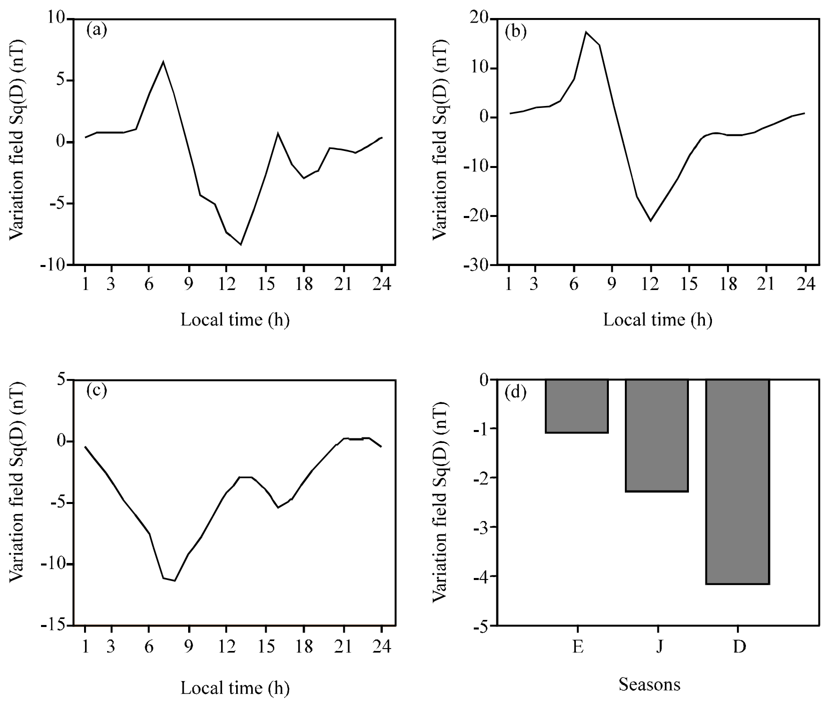

Fig. 6: (a) Diurnal variation of S_qD for October, (b) Diurnal variation of S_qD for August, (c) Diurnal variation of S_qD for December and (d) Seasonal variation of MQD

That is, IHFACs had the tendencies of flowing more westward in the winter during morning and in the summer during noon and dusk in the northern hemisphere. It also flows more westward in the summer in the morning and in the winter during noon and dusk in the southern hemisphere.

Chapman and Ferraro (1931) result is consistent with our results shown in Fig. 6a-c. This shows the local time dependence of MQD at Ilorin in October, August and December respectively in 2008. The MQD between 0100 Hr LT and 0500 h LT is positive, it showed significant positive increase till 0700 h LT in August and October and negative trends in December. The MQD experience reversal current that is, decreases negatively between 0800 h LT and 1200 h LT and increases until 2300 h LT in August. In October, reversal current is also experience because MQD decreases negatively between 0800 h LT and 1300 h LT, positive increases until 1600 h LT and then sluggishly decreases negatively till 2300 h LT. The month of December experience significant MQD reversal current throughout its period, though varying in magnitudes.

These results are supported by Fukushima (1994), Lesur *et al.* (2005) and Vennnerstrom *et al.* (2007), that is the existence of IHFACs in the summer and winter northern-hemisphere during the dawn, noon and dusk sectors.

The months of August and October revealed that the declination changes on local time dependence is more eastward and positive in the summer northern-hemisphere during dawn and is more westward and negative in the summer northern-hemisphere during noon and dusk.

The month of December also support IHFAC system (IHFACs) such that the change in declination on local dependence is more westward and negative in the winter Northern-hemisphere during the dawn sector. From noon through dusk, declination changes on local time dependence is more westward and negative in the summer Northern-hemisphere. IHFACs current intensity in the dusk sector is strongest in the month of December follow by the month of August and the least in the month of October. This dusk sector current intensity of IHFACs effect from previous studies could not be proved Takeda (1990). Yamashita and Iyemori (2002) also supported Takeda (1990) and contradicted our results by concluding that the IHFACs at the dusk sector is weak, no clear evidence or there might be another current system that cancels the effect of the duskside IHFACs on the ground.

Seasonal variation of MQD: Seasonal variation exists in the month of August, October and December (Fig. 6d). These months were investigated, reveal the existence of TEFACs and give quantitative information in terms of magnitude of the seasonal values in this region.

The current intensity of TEFACs at Equinox is maximum with magnitude -1.1821 nT, showing that height of the plot bar is high and has tendencies to vanish. The current intensity is minimum at the solstices with plot bar having highest height at December solstice and the plot bar higher at June solstice. Figure 4d showed that the magnitude of current intensity of MQD at the Equinox is represented by E-season, magnitude of current intensity at June solstice represented by J-season is -2.3782 nT and the magnitude of current intensity at December solstice represented by D-season is -4.2564 nT. This shows that the magnitude at J-season is greater than the D-season. These results are in consistent with Fukushima (1994) results. Yamashita and Iyemori (2002) seasonal results also contradicted ours because they concluded that MQD does not have tendencies or vanish at the Equinoxes and does not become largest at the solstices.

CONCLUSIONS

Magnetic data obtained from Magnetic Data Acquisition System (MAGDAS) was used to investigate ionospheric current intensity in all the three components H, D and Z. Ionospheric currents S_qH (Fig. 3-5a) and S_qZ (Fig. 3-5c) variations were observed and S_qD (Fig. 3-5b and 6a-d) revealed the existence of IHFACs and TEFACs.

Ionospheric currents S_qH and S_qZ variations are sometimes (Fig. 4, 5) compatible because both variations rises at about the sunrise 0600 h LT, peaks at about local noon and a gentle fall at about sunset 1800 h LT and incompatible (Fig. 3) at 0600 h which need further clarification. Despite the compatibihty (Fig. 4, 5), magnitudes of S_q in H at any hour of the day are greater than those of the S_q in D and Z. The three components also exhibited night-time variation characteristics (Fig. 3-5).

The Inter-Hemispheric Field-Aligned System (IHFACs) is responsible for the diurnal and mean monthly variation of S_qD. S_qD magnitudes and variations were clearly confirmed during the dusk sector by MAGDAS, which proves IHFACs existence in the evening (Fig. 6a-c).

Trans-Equatorial Field-Aligned Current System (TEFACs) is responsible for seasonal S_qD (Fig. 6d) and has tendencies to flip their direction at Equinox because its magnitude is maximum. TEFACs have minimum magnitudes at June and December solstices with the least magnitude accounted for at December solstice.

MAGDAS magnetometer have prove itself to be a powerful and reliable tools to investigate the magnetosphere-ionosphere coupling structures of S_qD, (Fig. 1) mainly during the dawn to dusk sector of inter-hemispheric field-aligned currents and seasonal dependence on trans-equatorial field-aligned currents.

Further effort in the second part of this publication shall focus on investigating the complete nature of IHFACs and TEFACs, especially the controversial duskside IHFACs using more data set from Magnetic Data Acquisition System (MAGDAS) that would cover all the months in the year at Ilorin.

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