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Daily, Seasonal and Monthly Variation of Middle-low latitudes Magnetic Field during Low Solar Activity

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ABSTRACT

The variation of horizontal component of the geomagnetic field (Sq-H) is taken in the year 2003 to study the diurnal, monthly as well as seasonal variation of Sq-H using 4 geomagnetic stations across various latitudes and longitudes. We have carried out this work on "Variation of Horizontal Component of Magnetic Field in Low Solar Activity" to understand the variation of solar quite (Sq) current and its effect on the Earth's surface. The geomagnetic daily variations in the ionosphere are produced by electric currents. We studied the variation of Sq current over the various 4 quietest days of February 2003. Results show that Sq (H) exhibits transient variations with varying amplitude according to seasons and days of the year 2003. The analysis was carried out on solar quiet days using hourly values of horizontal H component of geomagnetic field. The variations of Sq-H are mainly characterized maximum around the daytime (0700–1700 LT) and the minimum around pre-sunrise (0500–0600 LT) and the nighttime (1800–0400 LT). These results show that the Sq-H have consistent minimum values during pre-sunrise hours between 0500 and 0600 LT. The maxima and minima values of Sq-H observed from the pre-sunrise towards the sunrise period may be characterized by counter electrojet.

Keywords: Ionosphere, solar quiet, Counter electrojet, Equatorial electrojet.

1. INTRODUCTION

The geomagnetic daily variations in the ionosphere are produced by electric currents (Stewart, 1982). The upper layer of atmosphere ranging from 60 km to 1000 km above the earth is ionized by solar and cosmic radiations is known as ionosphere (Obiekezie et al., 2013). Because of the high energy and cosmic rays, the atom in this region undergoes photo ionization. Thus, the atoms in this region are in ionized state. This layer is conducting due to the presence of partly ionized plasma. The conducting plasma is driven by wind and the thermal tide motion in the E-region (i.e. the layer of 50-90 miles of ionosphere) causing solar-quiet (Sq) current system (Obiekezie et al., 2013). The prevailing wind in the ionosphere was observed by Alex et al. (1992), which cause currents to flow at altitudes between 100 km and 130 km. As suggested by Brown et. al., (1969) the semi-diurnal component of the wind generates diurnal wind and day to day variability which produce average diurnal feature of the observed Sq pattern. The neutral wind is mainly caused by the migrating tides. This changes the structure of the equatorial electrojet (EEJ) (Doumbia et al., 2007).

The predominant wind is the wind system, which is fixed with respect to the position of sun but varying the direction (Matsushaita, 1967). Across the Earth's magnetic field, the predominant wind will transport the conducting plasma that generates the current. As a result, the geomagnetic perturbations occur at the ground (Campbell, 1989). A regular variation of the geomagnetic field, known as the Sq daily variation, is recorded at mid-low latitudes (Chapman, 1919). The Sq current system is composed of two large current vortices on either side of the magnetic equator. Among them, the first one is following anticlockwise in northern hemisphere and the next is following clockwise in southern hemisphere. As the earth rotate inside the Sq current system, the geographic location is subjected to the perturbation. Such perturbations are associated with different parts of current system causing the daily variations (Barbas, 2013). According to Stening (1970), the combination of migrating and non-migrating components is the driving source of Sq current. The daily variation of the geomagnetic field component is due to the Sq current and equatorial electro jet (EEJ) (Rabiu, Nagarajan, 2008). The Sq current flows eastward at a lower altitude of 113 ± 7 km, whereas the EEJ current flows either eastward or westward at lower altitude of 107 ± 8 km, which is observed and explained by Chapman (1951), Richmond (1973), Onwumechili (1997), Bolagi et al. (2013). The Sq magnitude will be enhanced, if both the Sq and EEJ currents are flowing eastward. Counter electrojet will be produced if the Sq and EEJ are flowing opposite to each other such that westward EEJ currents exceeds the eastward Sq current. The stronger eastward current flows within the E region of the ionosphere called EEJ due to the increase in Sq current.

A regular variation is a day- to- day variation, which depends on the phase of the sunspot cycle, seasons, movement of the solar quiet foci, atmospheric tide and longitude. It is also called as Sq(H) (solar quiet variation) (Rastogi, 1993). It shows seasonal behavior with a maximum and minimum in local summer and local winter respectively at high and mid-low latitudes (Greener and Schlapp 1968). It shows maximum at the equinox in the inter-tropical area for H and Z components (Schlapp, 1968; Khalil et al., 2014). The daily variability of Sq(H) reflects a greater coherent length in the east-west direction as compared to north-south direction (Greener and Schlapp, 1968). Two large vortices of electric currents in the day-side ionosphere help to generate it. The dynamo current that flows in ionosphere at 20 degree latitude as a result of tidal motion in atmosphere across geomagnetic field is responsible for it. These vortices are centered at 40 degree latitude near the Sun meridian (Chapman, 1951; Onwumechili, 1997; Bolagi et. al, 2013). At the level of the equator, there is a concentration of the current (west-east) called equatorial electrojet (Rabiu,Nagarajan, 2007). It leads to a daily variation value up to 200 nT. The contribution of irregular variations of geomagnetic field can be defined as: one contribution characterizes the actual magnetic storm and the other represents the variations depending on local time (magnetic sub storms). Other irregular variations revealed by the observatories in mid latitude are called convection bays that are seen during the evening and night time for about 1-2 hours. The ionospheric currents flowing at latitudes between 65-70 degree along magnetic field lines are the main sources for these bays. The solar cycle can explain the seasonal variation of Sq(H). There are seasonal variations of Sq current from low to midlatitudes (Campbell 1988; Mansilla, 2014). On the other hand, observatories on high latitudes show annual variations of Sq current as a result of large ionospheric conductivity differences between winter season and summer season. In equinoxes, the solar zenith angle is minimum whereas in both solstices at mid-low altitudes, the angle is maximum.. This is the main cause for large conductivities in ionosphere at equinoxes. However, the variations in amplitude of Sq seasonally at low-mid latitudes are not adequate to be observed due to the equatorial electrojet (Rastogi, 1974; Onwumechili, 1997). This is because the equatorial electrojet show variation semi-annually. (Chapman and Rajarao, 1965; Stening, 1995).

This paper analyze the geomagnetic data to investigate the nature of horizontal component of magnetic field (H) due to ionospheric current (Sq-H) variations at four different stations located at different latitude and longitudes during low solar activity in the years of 2003. The database and methodology for this work has been presented in section 2, results and discussion in the section 3, whereas Section 4 gives a concise conclusion of the results presented in the work.

2. DATABASE AND METHODOLOGY

For the study of daily, monthly and seasonal variation of SqH during the low solar activity days, we have taken the data from different stations (i.e. Guam, Alibag, Vassouras, Kakioka) from the website:-www.intermagnet.org. The lists of ground stations with their geomagnetic coordinates are shown in the table below.

Table 1 The location of magnetic observatories stations

S.N.	STATION	NAME	COUNTRY	GEOMAGNETIC(°)	
				Latitude	Longitude
1	ABG	ALIBAG	INDIA	10.0	146.0
2	GUA	GUAM	USA	5.1	215.4
3	KAK	KAKIOKA	JAPAN	27.2	208.5
4	VSS	VASSOURAS	BRAZIL	-13.4	27.1

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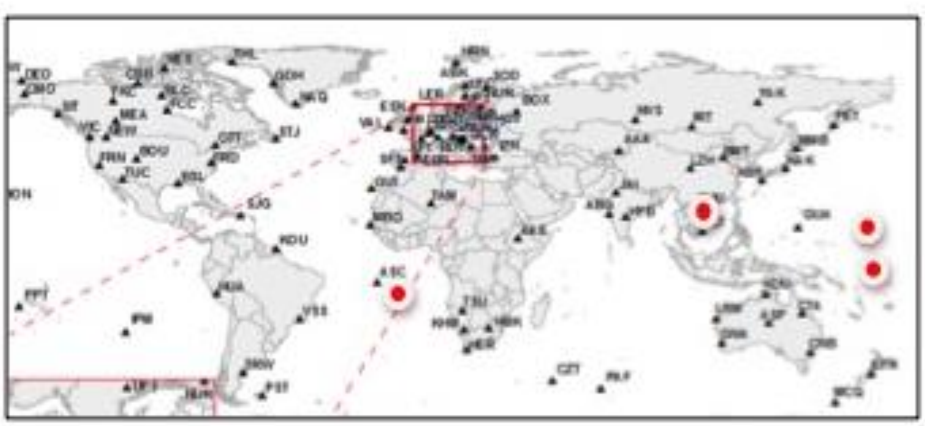

Figure 1 Map of magnetic observatories stations represented by red dotted circles

In order to achieve the set targets of this work, the data for horizontal component of magnetic field on low solar quiet days at four different geomagnetic observatories stations Guam (geomagnetic latitude 5.1°**N,** longitude 215.4°**E**), Alibag (geomagnetic latitude10.0°**N**, longitude146.0°**E**), Vassouras (geomagnetic latitude 13.4°**S**, longitude 27.11°**E**) and Kakioka (geomagnetic latitude 27.2 °**N**, longitude 208.5°**E**) for 5 days of February month, all the months and all the seasons of the year 2003 were obtained from the website: www.intermagnet.org. The 1 min records of the north-south geomagnetic component (H) are converted to hourly values in the given sets of data. From the one minute records of H, average values were found that were considered to be centered at the local time (LT). Guam station is 10 h ahead of Greenwich Mean Time (GMT) therefore, 1200 UT is 2200 LT in Guam, Alibag is 5h 30 min ahead of Greenwich Mean Time (GMT) therefore, 1200 UT is 1730 LT in Alibag, Vassouras is 3h behind of Greenwich Mean Time (GMT) therefore, 1200 UT is 0900 LT in Vassouras and Kakioka is 9h ahead of Greenwich Mean Time (GMT) therefore, 1200 UT is 2100 LT in Kakioka. By the calculation of the average value on hourly basis of 4h flanking local midnight (0100, 0200, 2300 and 2400 LT), the baseline value (BL value) was found. The expression for BL value of horizontal component (H) is given by

$$BL = \frac{H0100 + H0200 + H2300 + H2400}{4} \quad \text{......} (1)$$

Here, the BL value thus obtained is corrected to the nearest whole number in the unit of nano-Tesla. H0100, H0200, H2300 and H2400 are the hourly values of the H-components at 0100, 0200, 2300 and 2400 LT respectively. When the BL value of a given day was subtracted from every hourly values of the same day, the Hhd (Hourly departure of H-component) was obtained that has nearly equal value to hourly solar quiet of H-component.

$S_qH_t = H_t – BL$ .... (2)

Where "t" indicates the time in hours and which ranged from 0100 to 2400 LT, SqHt indicates the hourly solar quiet of H-component.

3. RESULTS AND DISCUSSION

3.1. Daily Variations of Sq-H

The Sq-H values, that were obtained after measuring the geomagnetic element of horizontal intensity (H), were calculated for all the days in the year 2003. Every month of each year have the quietest days. February month had fifteen quiet days. In January, 21 quiet days are obtainable whereas in August, 22 quiet days are obtainable. In all remaining months except April and May, more than 22 quiet days are obtainable whereas for April and May, only 20 quiet days are obtainable.

In 2003, four of the quietest days of February were considered for observations of how horizontal component (H) of magnetic field varied on a daily basis as a result of Sq current. These days are as follows:- (i) 11th February, (ii) 13th February, (iii) 23th February, (iv) 24th February. To observe the daily variation, we took the data from different 4 stations i.e. Guam, Alibag, Vassouras and Kakioka. We plotted local time in hours along the x-axis and magnetic field in nano-Tesla (nT) along y-axis. The curve in black colour indicates the daily variation of Sq current taken from Guam station, red curve indicates for Vassouras station, green curve indicates for the Alibag station whereas the curve in blue color indicates the daily variation of Sq current taken from the Kakioka station.

In Figure 2, the variations of Sq-H are mainly characterized maximum around the daytime (0700–1700 LT) and the minimum around pre-sunrise (0500–0600 LT) and the nighttime (1800–0400 LT). At the pre-sunrise time from 0500 to 0600 LT, the Sq-H values are consistently minimum as indicated by the results. They rise steeply during the sunrise period (0700–0900 LT) and show peaks during the daytime mostly around 1000LT–1200 LT except Kakioka. The Counter Electroject i.e. CEJ can characterize the Sq-H minima and Sq-H maxima values that are obtained from the observations carried out from pre-sunrise to the sunrise period (Gouin et. al., 1967). This CEJ could be clearly identified by a black line drawn on the base-line (zero) value of each plot. The LT variation of Sq-H below zero value shows CEJ. In general, the magnitudes of Sq-H and its variations were found to be larger before midnight than before sunrise hours. This clearly indicates that before sunrise, conductivities are low and the neutral pattern of wind caused by solar thermal heating is also absent. This absence of solar thermal heating causes the ionosphere conductivities to be the weakest during pre-sunrise hours over all the days throughout the year 2003 (Bartels et al., 1940).

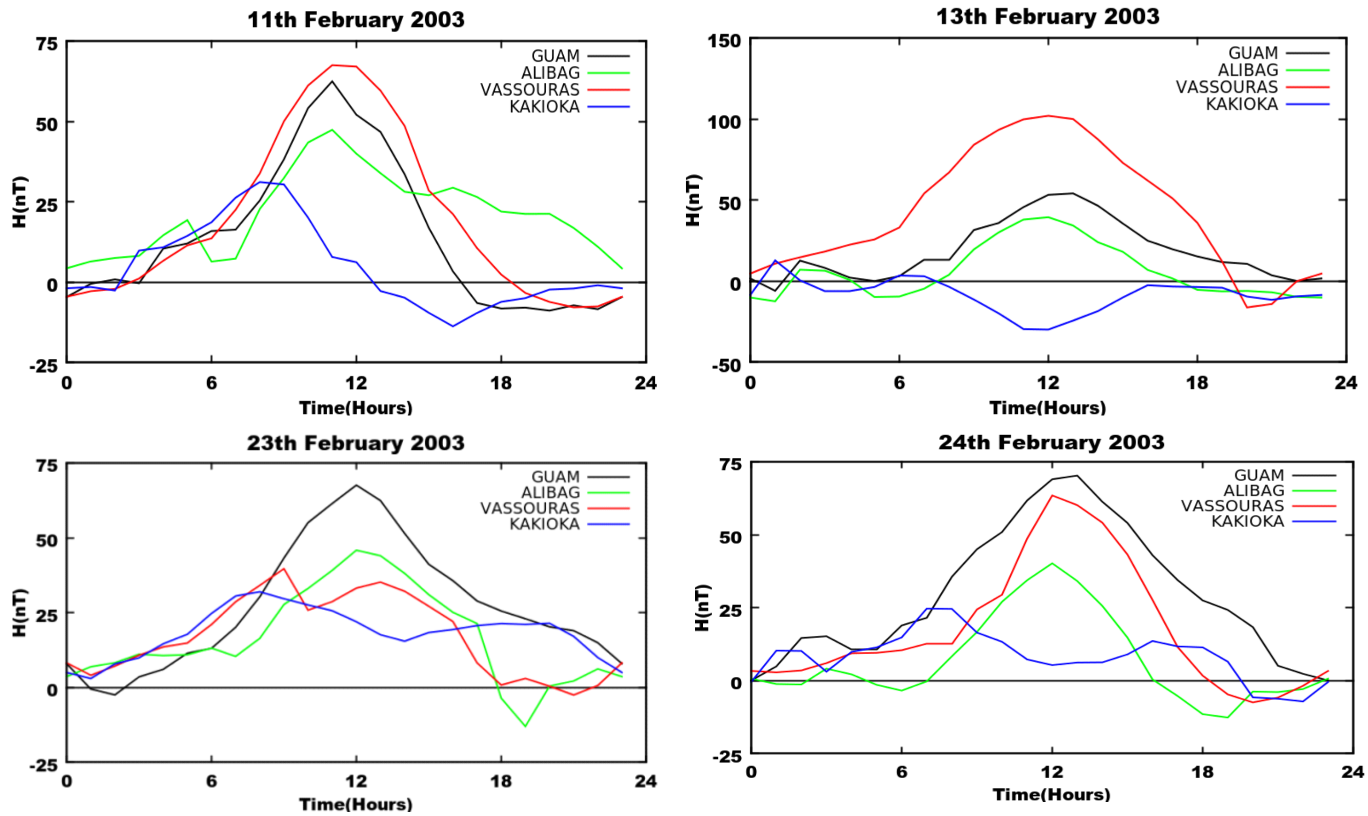

Figure 2 Plot of SqH from the stations: Guam (Black), Alibag (Green), Vassouras (Red), Kakioka (Blue) on February 11, 13, 23, and 24, 2003.

These observations have been previously reported by Bartels et al. (1940) Onwumechili et al. (1962, 1967) and Rastogi, (1974). Okekeet al. (2000) reported that the SqH values during pre-sunrise hours are the lowest compare to during daytime hours. The daytime Sq-H maximum value occurs near noon hours (1100 LT-1200LT) in all days. The range of minimums that is obtained at nighttime (post-sunset and pre-sunrise) hours is less compared to the range of maximums obtained during the daytime hours of Sq-H in all days. The continuous solar heating of ionosphere causes the magnitudes to be greater during the daytime. During night, the absence of solar radiations means that there is no dissociation of ions in ionosphere. This indicates that any sort of variation obtained during the night time in different stations didn't come from magnetosphere and ionosphere but from some other sources. (Chapman, 1956).

The daily variation observed in Kakioka is different which can be attributed to the geomagnetic coordinate of Kakioka station being different than other stations mention above. That is Kakioka lies in the mid latitude whereas other stations lie in the low latitude. The variation also depends upon the types of used magnetometer i.e. the used magnetometer may be different for the different stations. In other words, the pattern of Sq current flow and the ground conductivity could be the reasons behind different results obtained from Kakioka.

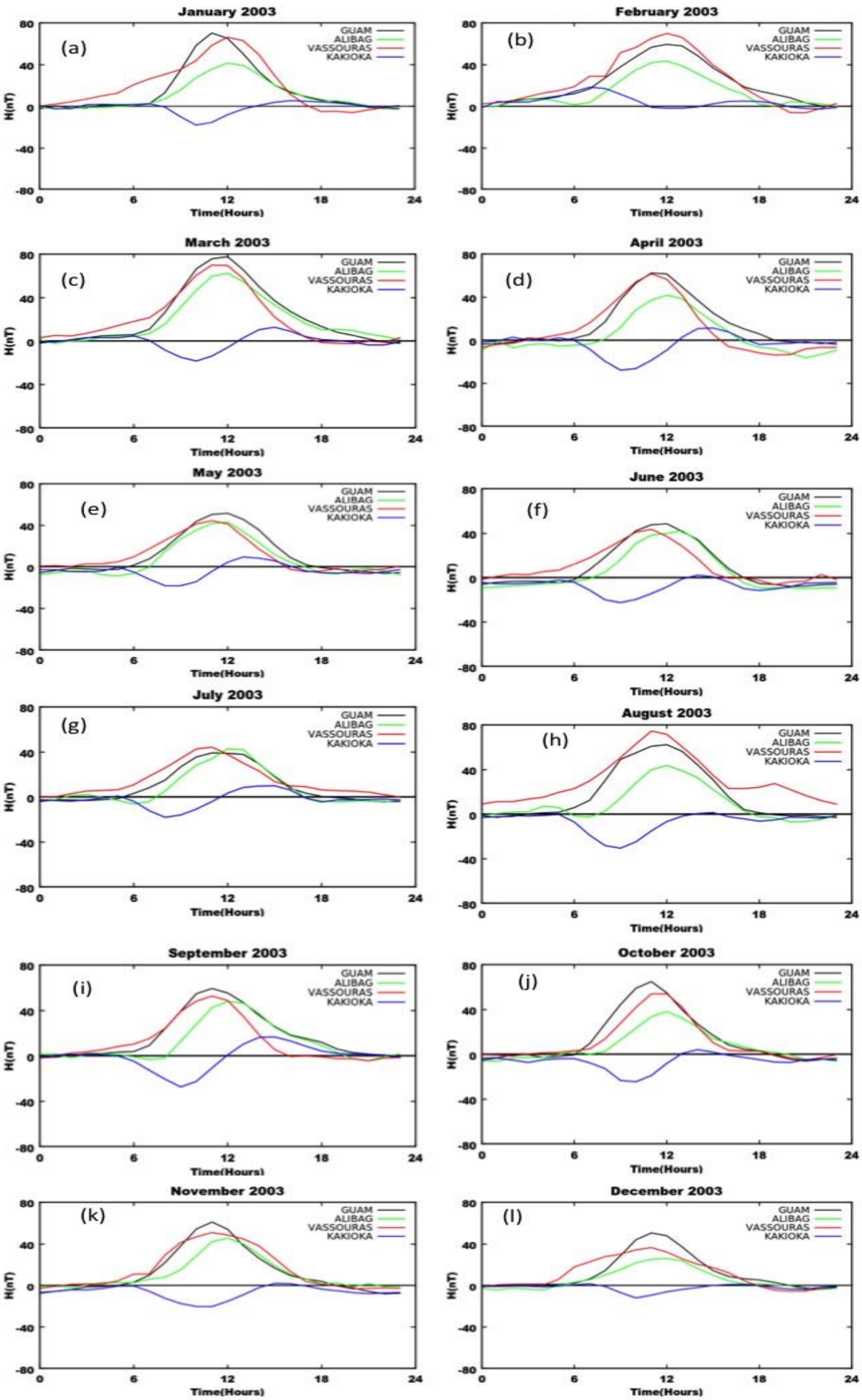

Figure 3 Plots of Sq-H from the stations: Guam (Black), Alibag (Green), Vassouras (Red), (Blue) on 12 months.

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3.2. Monthly Variation

All the days of a month are not quit days, each month doesn't have equal number of quit days. Further each month have number of quiet days depending upon the solar activity and its effect during the month. It should be noted that the same universal time doesn't resemble the same local time. That means same universal time corresponds to the different local time depending upon the longitude of that place. Universal time is the modern continuation of Greenwich Mean Time (GMT) used by scientist and is the time standard based on rotation of earth. It is a successor to Greenwich Meridian Time (GMT), although their exact definitions differ, and although GMT is no longer used within the worldwide community of scientists. For example, Greenwich Mean Time is same as universal time whereas one should subtract 9 hours from universal time to obtain Alaska Standard Time. To observe the monthly variation of Sq-H, we plotted the local time in hours (0000 to 2400 LT) along X-axis and magnitude of magnetic field in nano-Tesla (nT) along y-axis. Four different colors have been assigned in the graph to indicate the four different stations. Black, green, red and blue colored graph respectively represent Guam, Alibag, Vassouras and Kakioka.

Figure 3 shows the variations in magnitude of Sq-H for 12 months for different stations illustrating the similar nature of the monthly variations of Sq-H. The magnitude of variation is maximum during daytime (0700-1700LT) and minimum during night time (1800-0600 LT) during the all months. Further it is seen that, during pre-sunrise hours (0500-0600 LT) the value of Sq-H is minimum and these magnitude of Sq-H for all four stations rise sharply after sunrise (0600-0900 LT) and reaches the peak value approximately around 1000-1200 LT. It is seen that the variations of Sq-H for three stations Guam, Alibag and Vassouras are similar i.e. magnitude of Sq-H sharply increases, reaches at the peak point and finally decreases. However, the variation of Sq-H taking from Kakioka is slightly different. That is the variation of Sq-H is first decreases below the base line value, reaches to the lowest peak point and then increases.

The maximum variation in magnitude of Sq-H during daytime and minimum variation during the night time may be characterized by the absence of solar thermal heating which decrease the ionospheric conductivity at night time and increase its value after sunrise (Sclapp, 1968). The different pattern of graph for the Kakioka station in comparison to the other three stations may be due to the fact that this station is located at the mid latitude whereas other three stations are located at low latitude. Various ground conductivities, various kinds of magnetometers used at various stations, lunar tides electrojet and even counter electrojet may be the factors that affect magnitude of Sq-H (Rastogi, 1974). In most of the months during the year of 2003, the Vassouras station shows the rising value of Sq-H earlier than other three stations even in pre-sunrise hours. This may be due to hemispheric variation as it lies at southern Hemisphere (Stening, 1995).

3.3. Seasonal variation

We have studied how Sq current varies on seasonal basis: Winter (November to February), Summer(May to August), Autumn (September, October) and Spring (March, April), using data from 4 geomagnetic stations for the year 2003. The months having the length of day and night are of approximately equal, are equinoctial months (Rabiu et al., 2007). Equinoctial months fall during the autumn and spring seasons. And the months having unequal length of days and nights are solstices' months, these months fall during winter and summer seasons. To observe the seasonal variation of horizontal component of magnetic field due to Sq current, we plotted local time in hours along the x-axis and magnetic field in nT along the y-axis. In Figure 4, the curve having black color indicates that Sq-H in winter season, red curve indicates summer season, green curve indicates spring season whereas the curve having blue color indicates the autumn season.

In the Figure 4, it can be observed that the entire seasonal mean peaks around 1100-1200 LT with different magnitude except Kakioka station. For the Guam station, the greatest magnitude of magnetic field is obtained during the equinoctial months (March, April, September, October) and during solstices, winter (November, December, January, February), whereas the summer months (May, June, July, August) show the lowest magnitude in comparison to the equinox months. Thus, there is a semi-annual pattern in the seasonal variation with minimum during the solstice's months and maximum during the equinoctials months. Similar results obtained for the stations Alibag and Vassouras. This could be because these stations have similar geomagnetic coordinates in which the pattern of the flow of Sq current influences the ground conductivity.

However, the result obtained from Kakioka station shows the different result. This different Sq-H seasonal variation from Kakioka station can be attributed to the geomagnetic coordinate of station of Kakioka being different than other stations. That is Kakioka station lies in the mid latitude whereas other stations lie in the low latitude. The variation also depends upon the types of used magnetometer i.e. the types of used magnetometer may be different for the different stations. Also the Kakioka station may be influenced by the ground conductivity and the pattern of the flow of Sq current shows different for different seasons. Chapman et al.

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(1965) and Chandra et al. (1971) reported that greater equinoctial maxima observed on seasonal variations. The seasonal variations of Sq-H are explained on the basis of solar cycle, annual and semiannual variability. There are seasonal variations of the Sq current in the low to mid-latitudes (Campbell, 1988; Mansilla, 2014). On the other hand, the high latitude observatories show annual variations due to large ionospheric conductivity differences between winter and summer seasons. The solar zenith angle is minimum in equinoxes and maximum in both solstices at mid-low latitudes. This is the main cause for large ionospheric conductivities at equinoxes. However, the seasonal variations of the Sq amplitude at low-mid latitudes are not enough to be observed due to the presence of equatorial electrojet (Onwumechili, 1997, Adhikari and Chapagain, 2015, Adhikari et.al, 2016),). This is because the equatorial electrojet also exhibits a semiannual variation (Chapman and Rajarao, 1965; Stening, 1995, Bhattarai et.al 2016).

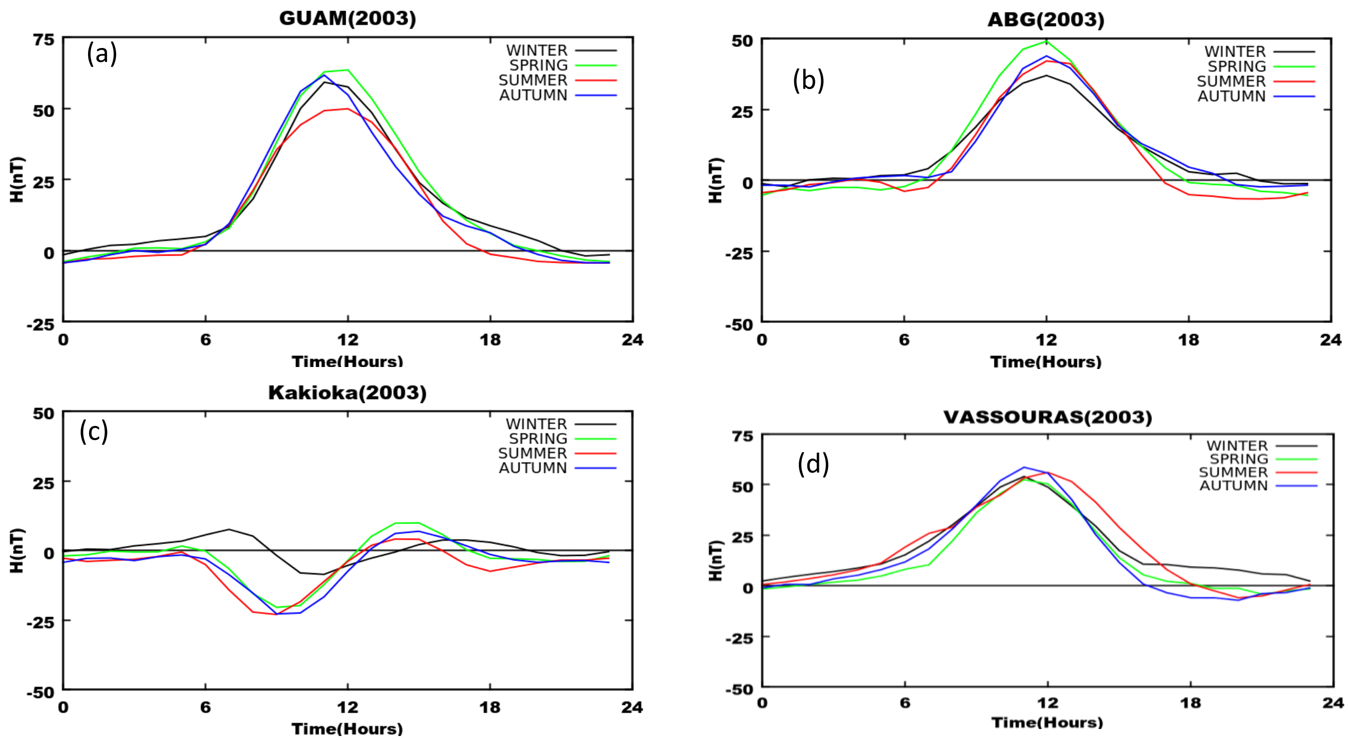

Figure 4 Plot of seasonal variation of Sq-H from the different stations at Guam, Alibag, Kakioka and Vassouras in 2003

4. CONCLUSION

This work also presents the variation of geomagnetic field horizontal component (Sq-H) at four geomagnetic observatories Guam, Alibag, Vassouras and Kakioka during low solar activity period and solar quiet days of each month of the year 2003. The diurnal variation shows the regular pattern in which magnitude of variation of Sq-H are greater in daytime than in night time for all the months. Minimum values of Sq-H, characterized by counter electrojet (CEJ) was observed during sunrise period, while the maximum value of Sq-H was observed during the daytime period (1100–1200 LT). The CEJ events were found to be frequent during the evening than the morning hours. Late reversal of nighttime westward currents to daytime eastward currents during sunrise period resulted to CEJ. The minimum night time variation indicates presence of other source of current other than equatorial electrojet (EEJ) i.e. counter electrojet. We also observed seasonal variations of the horizontal component of the magnetic field (H) due to Sq current and results show the pattern variations are similar for all seasons. However the magnitudes of magnetic field observed during spring season (equinoctial months) in general are quiet larger compared to other seasons. Thus, the seasonal variation shows a semi-annual pattern, maximum in equinoctials months and minimum in solstice's months.

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