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ORIGINAL RESEARCH ARTICLE

OCCURRENCE OF SIMILAR PERIODS IN GEOMAGNETIC FIELD VARIATIONS AND SOLAR ACTIVITY

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ABSTRACT

The periodicities associated with some geomagnetic field parameters under quiet and disturbed solar conditions have been examined using a set of data spanning through five years obtained courtesy of INTERMAGNET network. Hourly values of the Horizontal component of the geomagnetic field simultaneously obtained at seven INTERMAGNET stations were engaged in the study. The stations were well distributed across the latitudes, viz: Bangui, 4.4°N; Kourou, 5.1°N; Alibag, 18.6°N; San Juan18.1°N; Crozet, 46.4°S; Barrow,71.3°N; Scott Base, 77.9°S). Solar quiet daily variation Sq, Superposed Magnetic field SPMF and Solar disturbance daily variation SD in the horizontal magnetic field component were evaluated and studied for their spectral characteristics. The spectral analysis revealed the periods of 6 hours, 12 hours, 24 hours, 3 months, 6 months, 12 months and 16 months in the geomagnetic field variations. The observed periodicities were explained in terms of associated solar terrestrial processes. This clearly shows the influence of an extra terrestrial source (the Sun) on terrestrial processes. Sun is the undisputable driver of space weather

1.0 Introduction

The study of the ionosphere, and the region beyond it, has continued to attract attention due to its growing importance in several space-dependent technologies (Rabiu et al., 2007a). For example, Okoh et al. (2016) explained how ionospheric radio waves propagating through the ionosphere may experience frequency-dependent group delays as sources of error for the Global Navigation Satellite System (GNSS) and its dependent systems. The variability of ionospheric total electron content TEC has a very good practical importance in communication systems, and navigation control application (Ayorinde et al., 2016). Variations in the ionosphere often manifest as variability in the earth's magnetic field. The geomagnetic field pervades the region around the Earth, extending to several times the radius of the Earth. Sun related activity plays an important role in producing several electric and magnetic processes, which in turn affects the magnetic field of the Earth. The impact this activity has on the magnetic field of the Earth can be observed to follow a somewhat regular pattern.

Mursula and Zieger (2000) studied the occurrence of mid-term quasi-periodicities "MTQP" in solar wind "SW" speed since 1964 and in geomagnetic activity since 1932 and found that the spectral structure in the mid-term period range is very similar in these two variables over the whole common time interval of nearly 40 years of direct SW measurements. Prestes et al. (2006) observed that the 11-year solar cycle and the associated variability that it causes on the Earth's electromagnetical environment – the geospace- has been widely studied in the last decades. Nevertheless, the long-term relation between the solar and geomagnetic activity is a topic of intense research and it is not well understood at present (Gonzalez et al., 1990; Gorney, 1990; Cliver et al., 1996; Stamper et al., 1999; Echer et al., 2004).

The time rate of occurrence of a phenomenon is an essential concept in the scientific world, hence, scientists and meteorologists observe phenomena in terms of time series, as this gives a clearer description and understanding of such phenomenon and provide us with information on its periodicity. The space researchers have been able to use and are still using this tool to unravel the complex variations - both long-term and short-term - associated with the Earth's magnetic field. For example, researchers were able to deduce from time series observation a solar cycle of 11 years. This singular discovery has aided a better understanding of phenomenon and variations associated with the geomagnetic field.

This present study employed the fast Fourier transform to perform a spectral analysis on the hourly and monthly average time series of the solar quiet daily variation Sq, disturbance daily variation SD, and superposed magnetic field, SPMF of the horizontal component of earth's geomagnetic field from 1996 through 2002. The primary objective is to identify the probable occurrence of solar activity related periods in the variations of the geomagnetic components.

2. Methodology

The data set consists of hourly values of horizontal component of the geomagnetic field intensity, H, for the years 1996 to 2002, obtained at four equatorial stations: Bangui, Kourou, Alibag, and San Juan SJG; one middle latitude station: Crozet; two high latitude stations: Barrow and Scott Base. Table 1 presents the position coordinates of the stations. The data was obtained courtesy of the INTERMAGNET network. INTERMAGNET is a global network of observatories monitoring the earth's magnetic field. Hourly values of the horizontal component H of the geomagnetic field intensity on international quiet days IQDs and disturbed days IDDs for the years 1996 to 2002 were utilized in this study.

Table 1: Coordinates of the geomagnetic observatories

S/N	Location	Station Code	Geographical Coordinates	
			Latitude (°N)	Longitude (°E)
1	Bangui	BNG	4.4	18.5
2	Kourou	KOU	5.1	307.3
3	Alibag	ABG	18.6	72.9
4	San Juan	SJG	18.1	293.9
5	Crozet	CZT	-46.4	51.9
6	Barrow	BRW	71.3	203.4
7	Scott Base	SBA	-77.9	172.8

Daily variation baseline values were obtained from the mean of the four hourly values, of the horizontal component H of the geomagnetic field intensity on a particular day, flanking the local midnight- that is 1h LT, 2h LT, 23h LT, 24h LT. The daily baseline value is subtracted from the daily hourly values, to obtain the hourly midnight departure values. The hourly midnight departures were further corrected for the non-cyclic variation after Vestine (1967) and Rabiu et al., (2007b). The hourly departure corrected for non cyclic variation gave the corrected solar daily variation.

Solar quiet daily variation, Sq, was evaluated by estimating the solar daily variation as described above on international quiet days only. The monthly hourly means of the estimated values then gave the hourly Sq. Solar disturbed daily variation, Sd, was obtained by estimating the monthly hourly means of the solar daily variation on international disturbed days. The difference between Sd and Sq of a particular month is the monthly disturbance daily variation and is defined as:

$$SD = Sd - Sq \quad (1)$$

(Mitra, 1947; Rastogi, 2000)

We defined the Superposed Magnetic Field SPMF as follows:

$$SPMFt = Sqt - \text{mean}\ (Sqt) \quad (2)$$

where: SPMFt is the SPMF value at t h; Sqt is the hourly Sq value at t h; mean (Sqt) is the mean of the hourly Sq values for each individual t h, for the five international quietest days of month. SPMF is an improvement over the superposed field proposed by Onwumechili (1997) and is a measure of ionospheric contributions to geomagnetic field variations.

Periodograms shown in Figures 1 -7 are then obtained by the fast Fourier transform FFT technique using a MATLAB® based algorithm. Figures 1 and 2 show the spectra of the hourly Sq in Horizontal intensity of the geomagnetic field as obtained for the years 1996 and 1999 respectively. Figures 8, 9 and 10 present the spectra of the monthly averages of Sq, SD and SPMF respectively over the years 1996 – 2002 (84 months).

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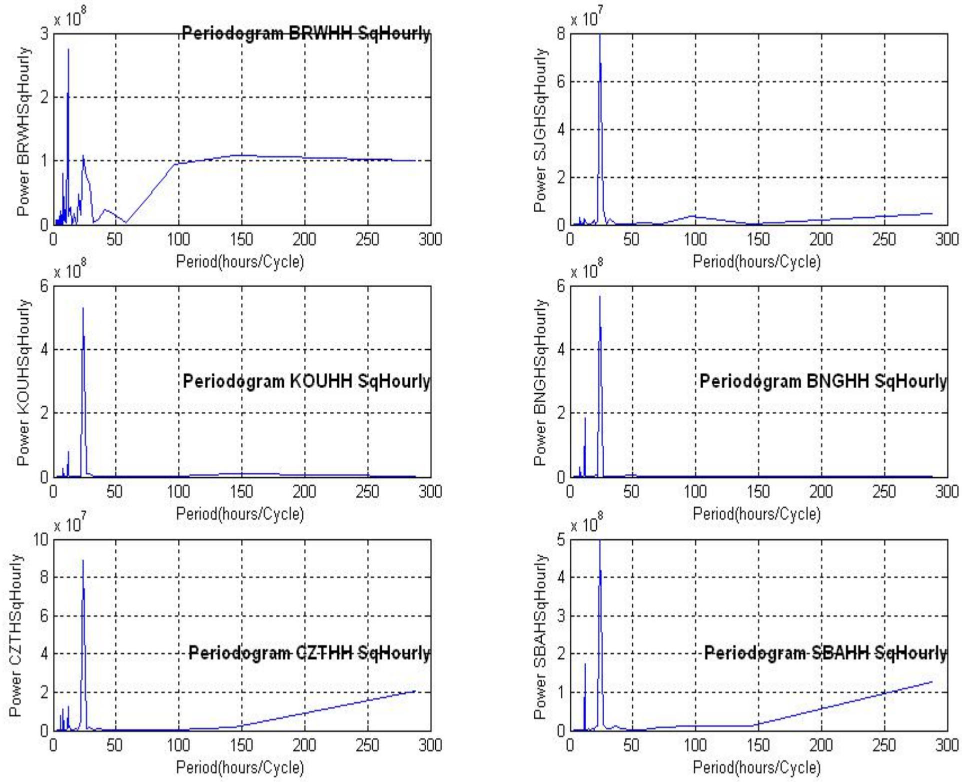

Figure 1: Periodograms showing the periods associated with Sq(H) hourly means for the year 1996

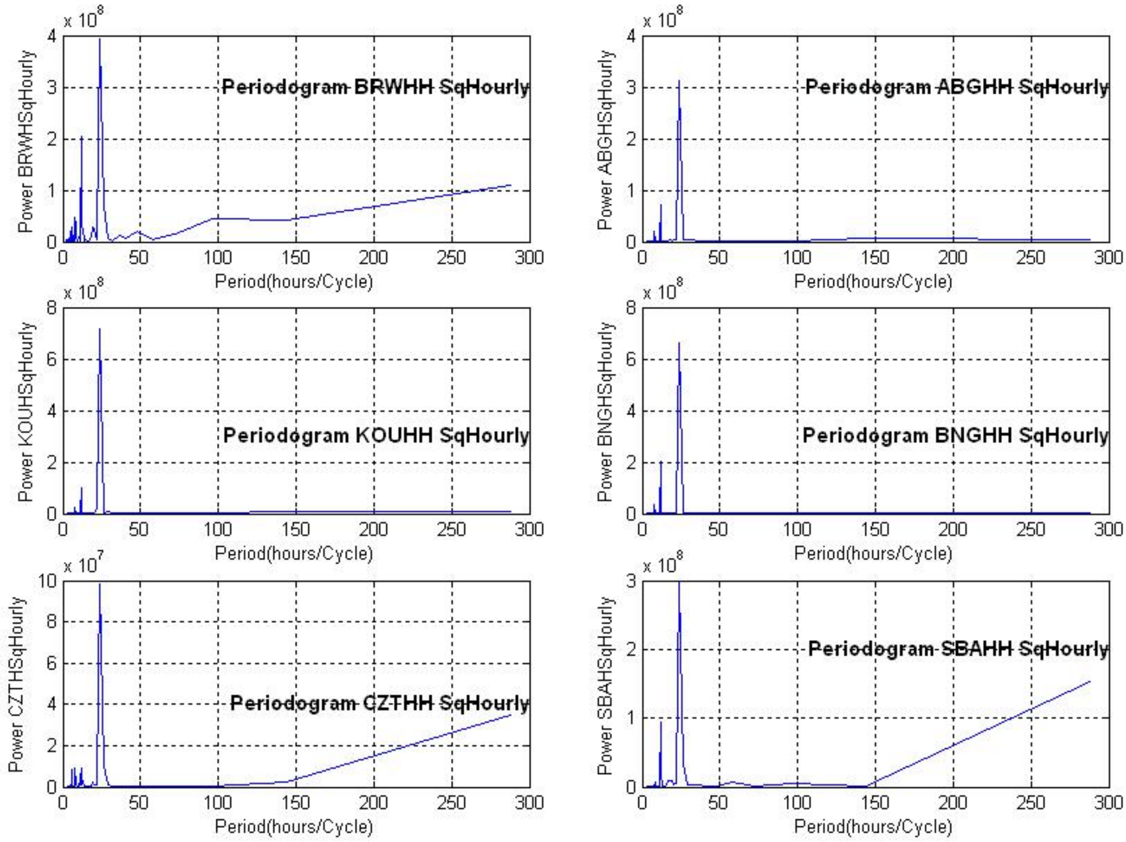

Figure 2: Periodograms showing the periods associated with Sq(H) hourly means for the year 1997

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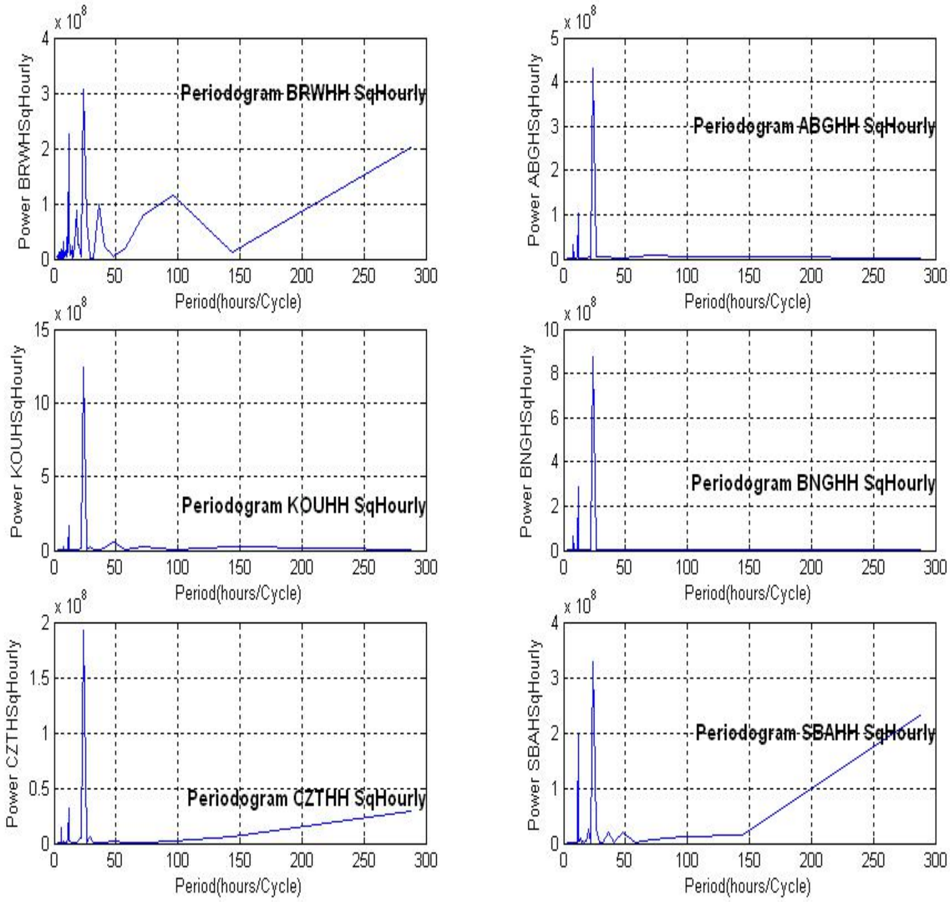

Figure 3: Periodograms showing the periods associated with Sq(H) hourly means for the year 1998

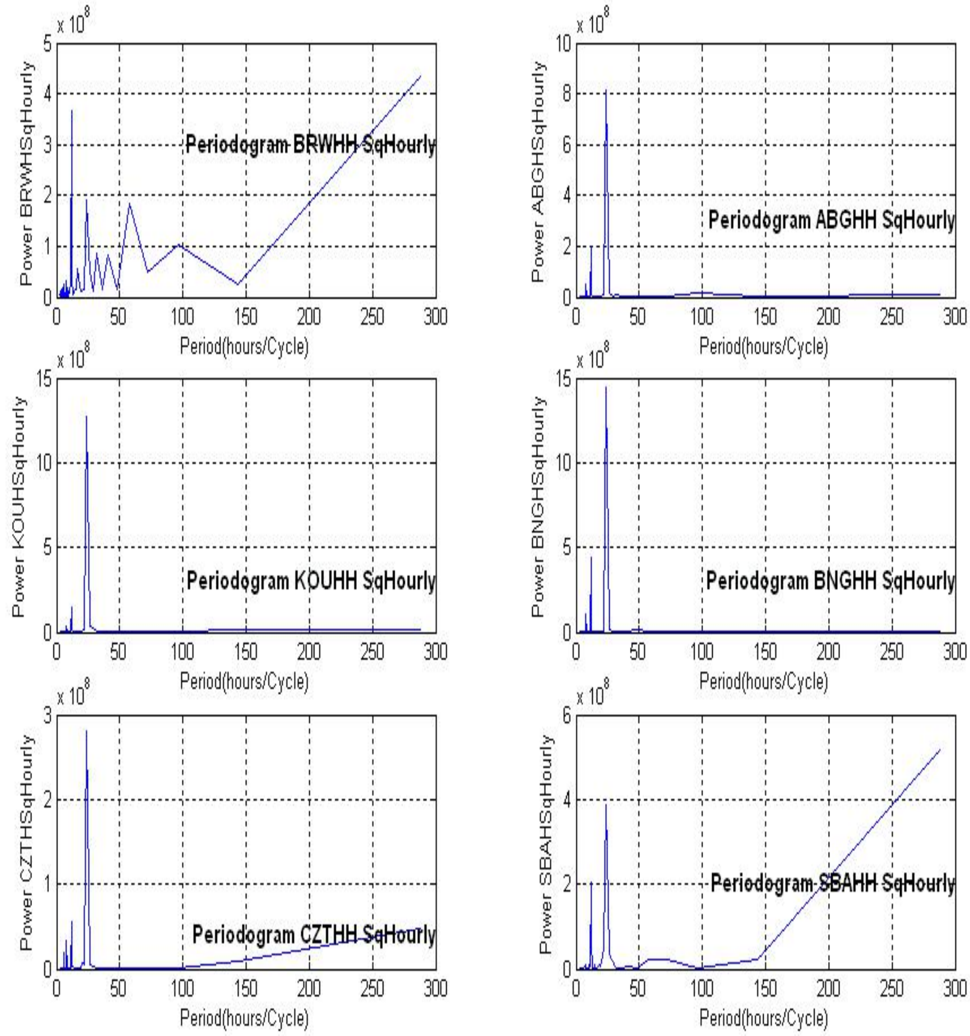

Figure 4: Periodograms showing the periods associated with Sq(H) hourly means for the year 1999

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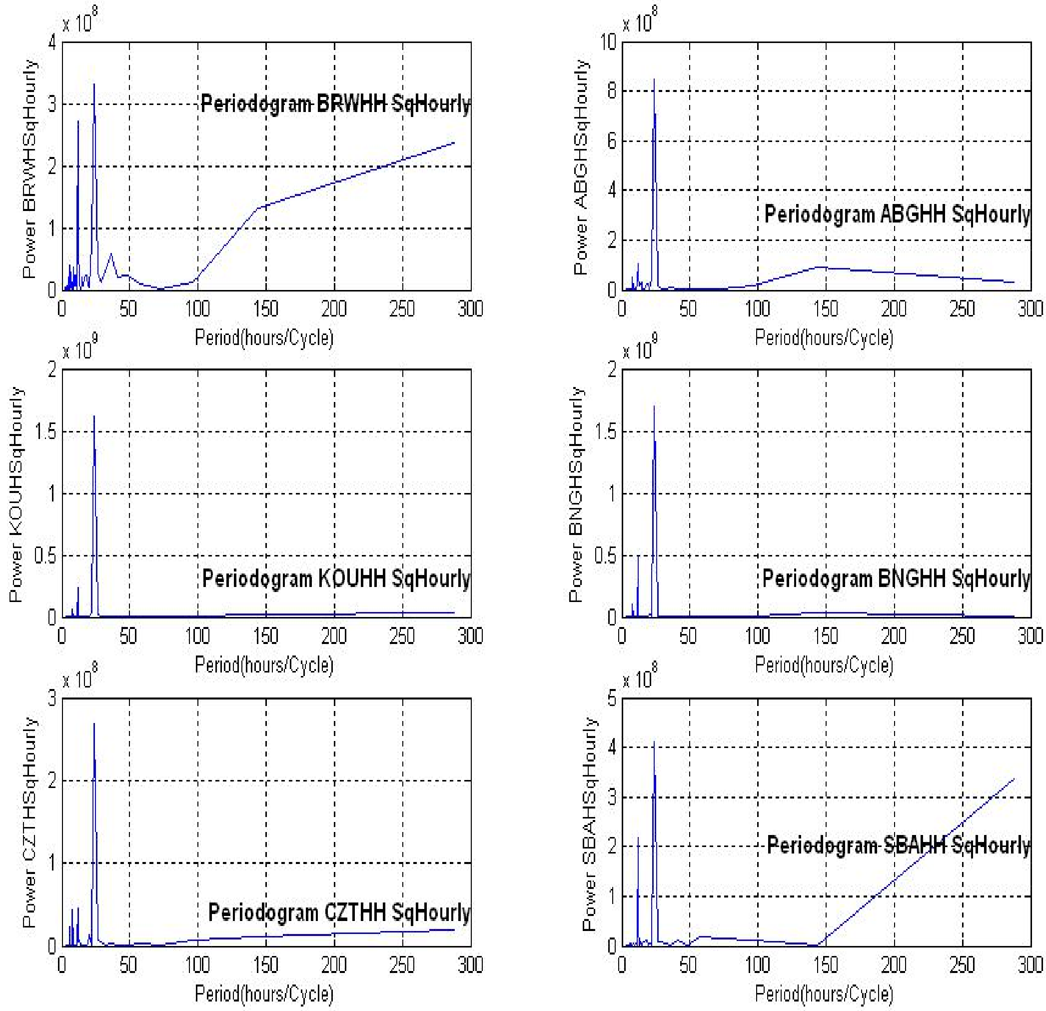

Figure 5: Periodograms showing the periods associated with Sq(H) hourly means for the year 2000

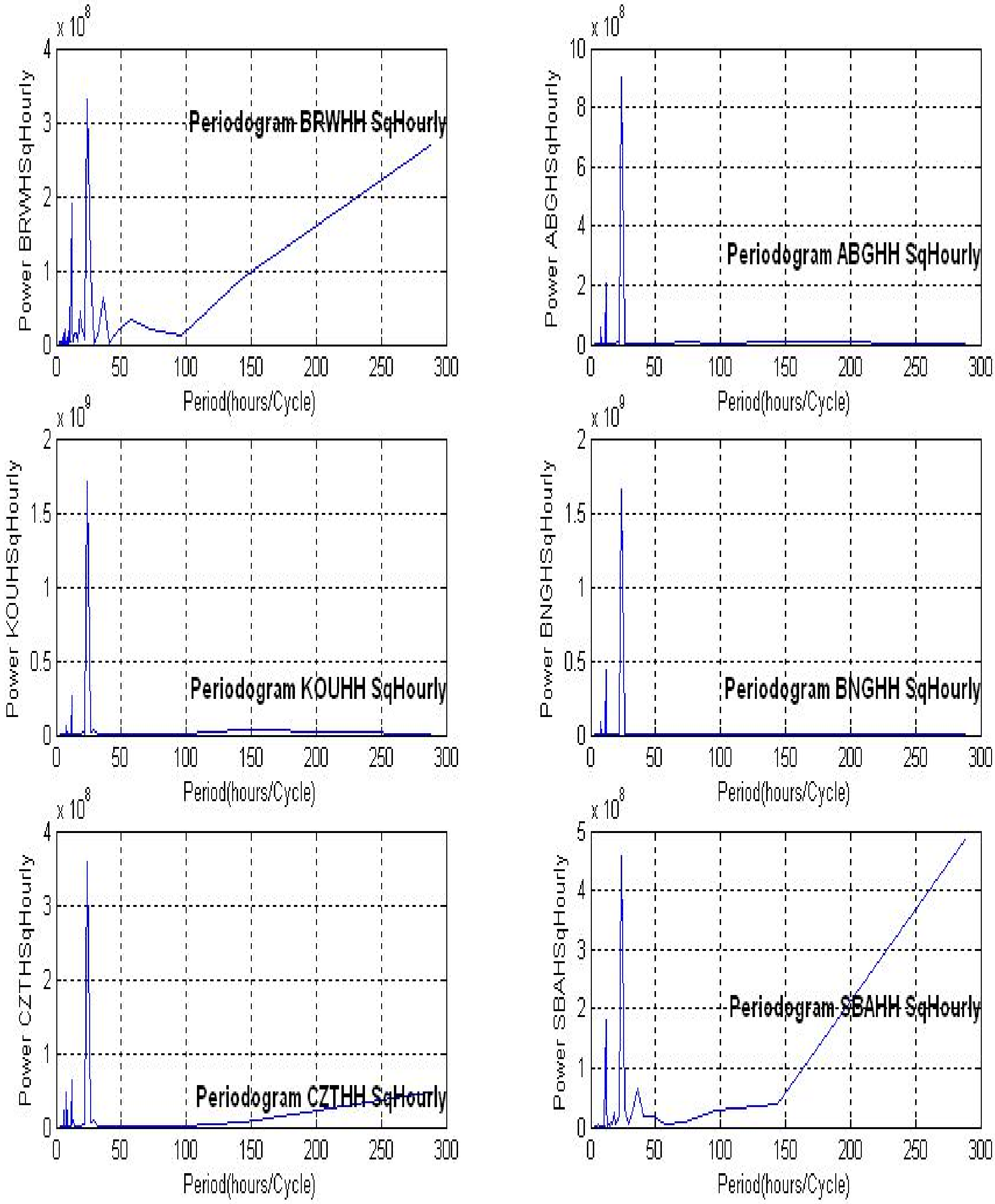

Figure 6: Periodograms showing the periods associated with Sq(H) hourly means for the year 2001

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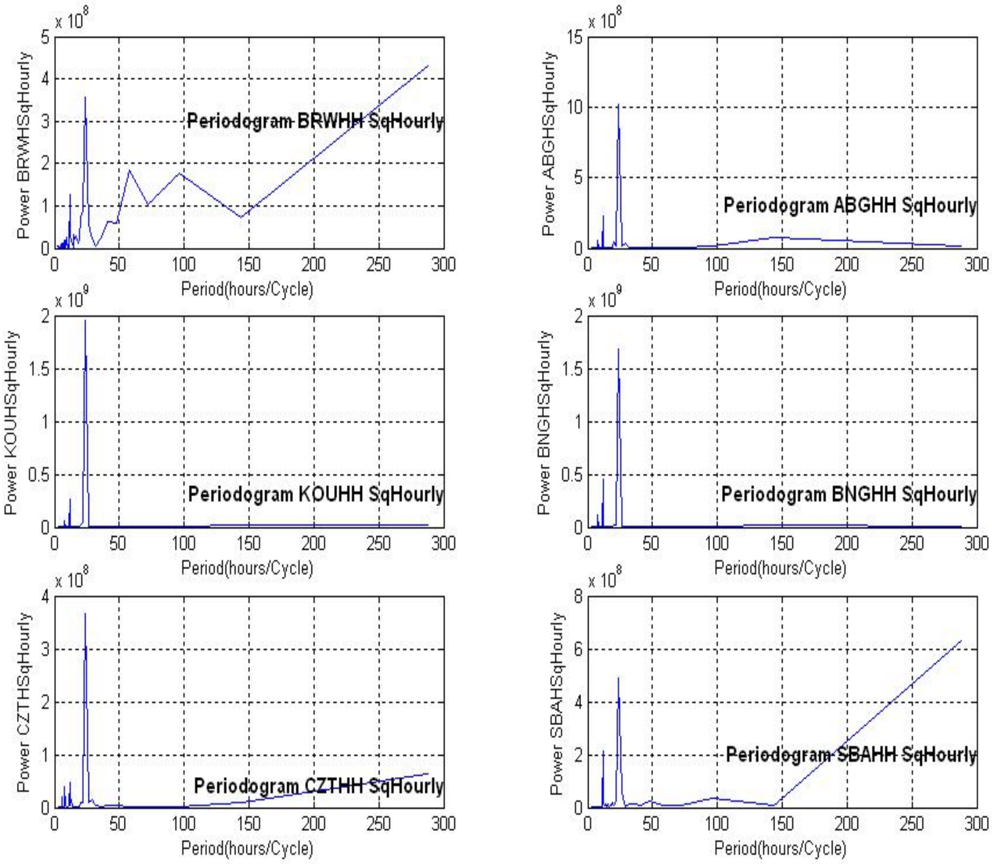

Figure 7: Periodograms showing the periods associated with Sq(H) hourly means for the year 2002

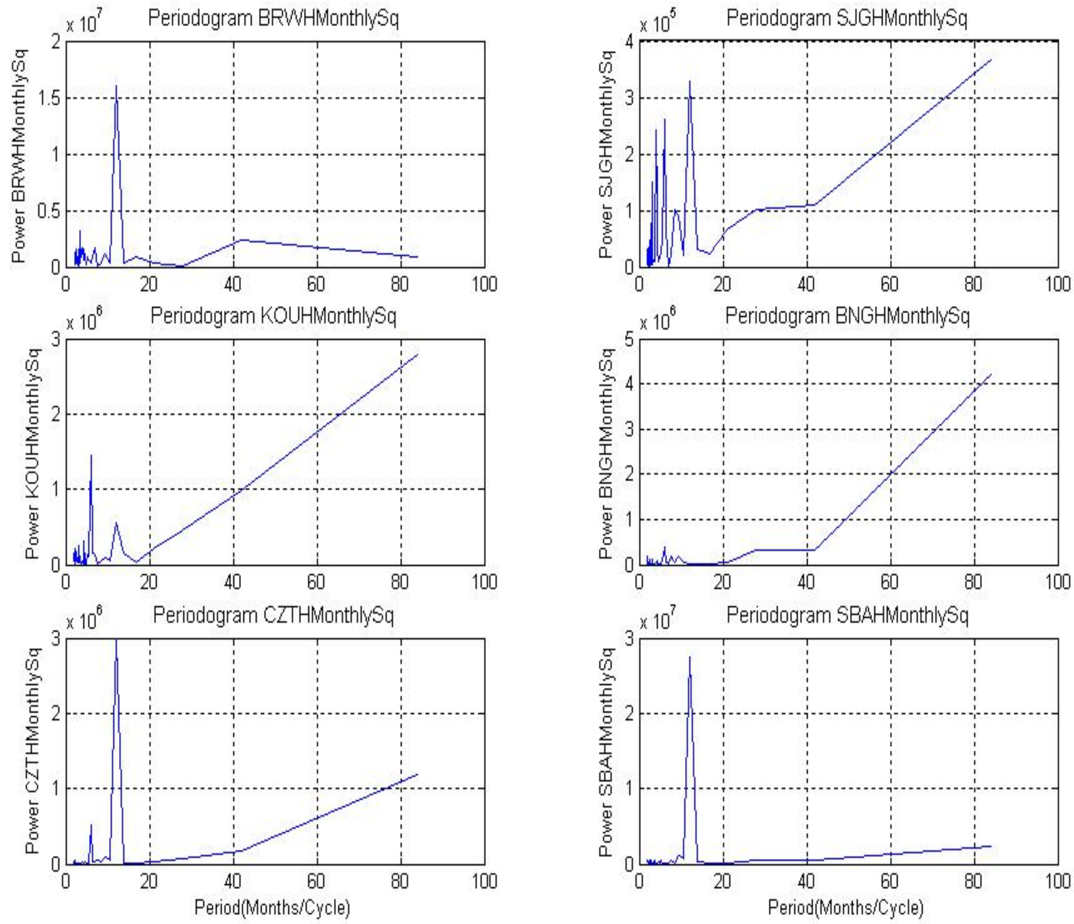

Figure 8: Periodograms showing the periods associated with Sq(H) monthly means

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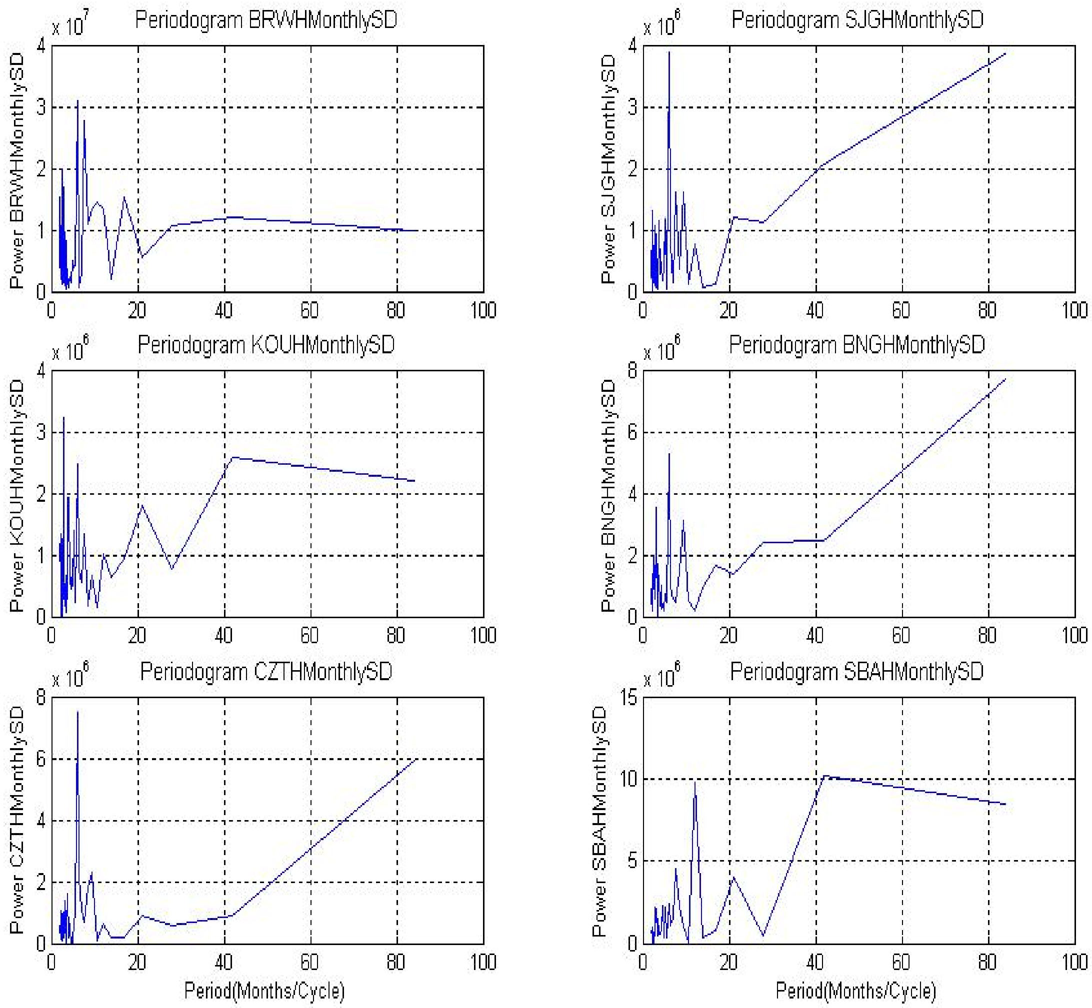

Figure 9: Periodograms showing the periods associated with SD(H) monthly means

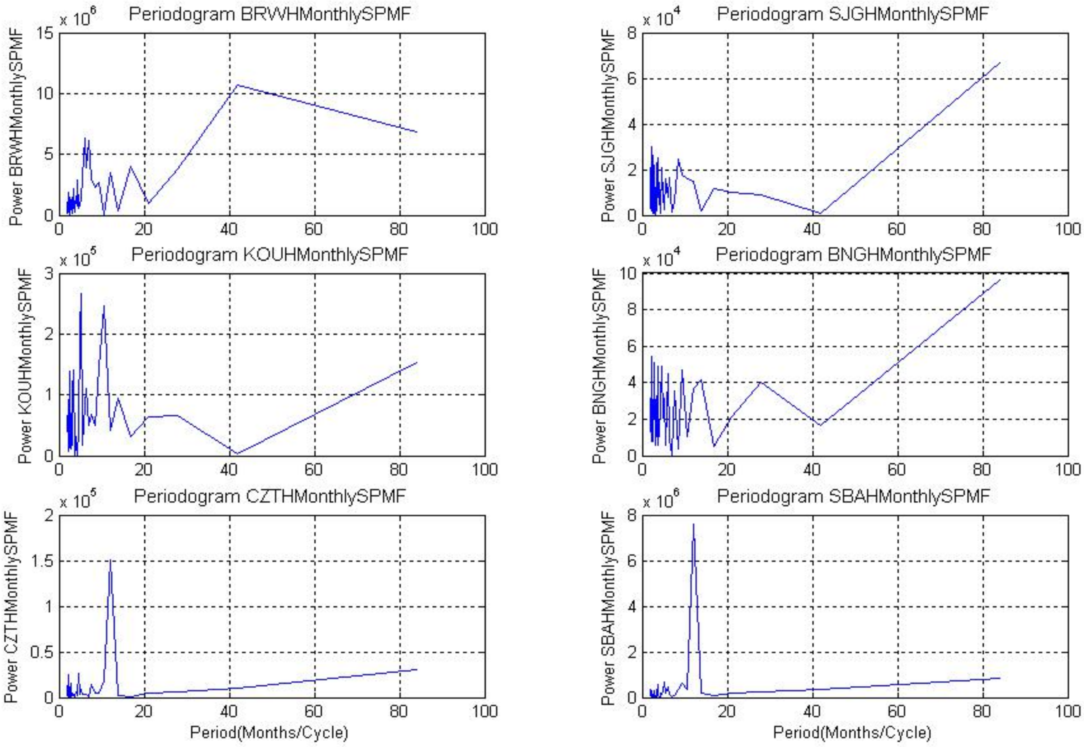

Figure 10: Periodograms showing the periods associated with SPMF (H) monthly means

Table 1 presents the obtained periods through FFT method of the hourly Sq (H) for each of the years 1996 - 2002. Table 2 shows the obtained periods of the monthly Sq, SD and SPMF series for the years 1996 – 2002.

Table 1: Periods associated with the Sq hourly means from 1996 through 2002

Station	Lat. (°)	Period (hours)						
		1996	1997	1998	1999	2000	2001	2002
BRW	71.32	8,12,24,42	6,8,12,24,36,48	12,18,24, 36	12,18,24,36,42,60,98	6,12,24,36	12,20, 24,36, 60	12,18,24 ,42, 60,98
ABG**	18.64	6,8,12,36	8,12,24	8,12, 24	8,12,24	8,12,24,48	8,12,24	8,12,24, 48
KOU	5.10	8,12,24	8,12,24	12,24,48	12,24	8,12,24	12,24	8,12,24
BNG	4.44	8,12,24	8,12,24	8,12, 24	8,12,24	8,12,24	8,12,24	8,12,24
CZT	-45.43	6,8,12,24	6,8,12,24	6,12, 24,30	6,8,12,24	6,8,12, 20,24	6,8,12, 24	6,8,12,24
SBA	-77.85	12,24,36	12,18,24, 60	12,20,24, 36,48	12,24,60	12,18,24, 42,60	12,18, 24,36	12,24,48, 98

*data for SJG and not ABG was used to evaluate hourly Sq in 1996.

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Table 2: Periods associated with Sq, SD and SPMF monthly means (1996-2002) as depicted by the peaks in the periodograms of the horizontal intensity (H)

Station	Geog Latitude (°)	Period (months) Sq	SD	SPMF
BRW	71.32	3,6,12,42	2,3,6,7,12,18	6,8,10,12,16,42
SJG	18.38	3,6,9,12	2,3,4,6,8,10,12,21	8,10,12,16
KOU	5.10	6,12	2,3,6,8,10,12,21,42	6,8,10,12,30
BNG	4.44	6	3,6,10,16	6,8,10,12
CZT	-45.43	6,12	3,6,9,12,21	6,10,12
SBA	-77.85	12	3,4,8,12,21,42	6,8,10,12

3. Results and Discussion

3.1. Sq(H) Hourly spectra

Table 1 presents clearly periods of 12-hour and 24-h as common to all the stations, irrespective of their latitudinal differences. The 24 h period signifies a 1-day periodicity in the observation which is reflected in the diurnal variation of Sq, while the 12-h period corresponds to semidiurnal variation which may be due to lunar modulation as proposed by Gouin (1962). This diurnal variation has been ascribed to the augmentation of the geomagnetic field by solar activity in daytime in consistency with the atmospheric dynamo theory of the geomagnetic variations (Onwumechili and Ezema, 1977). There are also additional periods (in hours) for the six stations as indicated in Table 1.

3.2. Monthly spectra of Sq(H), SD(H) and SPMF(H).

From Table 2, a 12-month period is noticed in each station except BNG. This represents a 12-month periodicity which is consistent with those observed in the planetary Sq variation and it indicates that Sq(H) undergoes an annual modulation which is mostly as a result of a 12-month oscillation (Arora et al., 1982). The non-prominence of the peak at the equatorial stations SJG and KOU corroborates Yacob's (1975) observation that the amplitude of the annual line does not show enhancement in the equatorial electrojet region. We also observe a 6-month periodicity which is common with those found in the planetary Sq semi-annual variation (Rabiu, 2001, 2004). While the 6-month and 12-month are expected there are additional periods of 3 months and 42 months in BRW and a period of 9 months in SJG. The 3- and 6-months periodicity manifested in form of seasonal variation of the Sq(H) which is solar controlled.

The monthly spectra of SD(H), as listed in Table 2, reveals the existence of a period of 6 months for all the six stations indicates a 6-month periodicity which is known to be associated with the semi-annual variation of geomagnetic activity (Prestes et al., 2006). There is also a period of 12-month, which is pronounced in the high latitude region BRW and SBA; and the middle latitude station CZT. As observed by Yacob (1975), this also indicates that the amplitude of oscillation does not show enhancement in the electrojet region.

The SPMF spectra yielded a period at the 12-month line in all the stations which indicates a 12-month periodicity of the H component under superposed magnetic field (See the 5th column of Table 2). There is also a peak at the 6-month line in all the six stations which signifies the 6-months periodicity associated with geomagnetic activity.

The seasonal variability depicted by the observed 3-months periodicity in Sq may be due to the ionospheric wind variations, atmospheric tidal forces, distant current systems such as current in the magnetosphere and the seasonal variation of the ionospheric electron current (Rabiu, 2001).

The 6-month period in Sq, SD and SPMF is obviously related to the semiannual variation of geomagnetic activity, which according to Prestes et al. (2006), is characterized by a greater geoeffectiveness at equinoxes than at solstices (Rabiu, 2001, 2004). This semi-annual variation may be due to the annual and semi-annual changes that are observed in the Earth's heating and ionization during the yearly path around the Sun (Campbell, 1982). This semiannual effect in geomagnetic activity is explicable in terms of three possible mechanisms: Russell–McPherron effect (RM), the equinoctial hypothesis and the axial hypothesis (Russell and McPherron, 1973; Clu´a de Gonzalez et al., 1993). The RM effect is a projection effect that depends on the season. The interplanetary magnetic field in the heliocentric coordinate system has a component in the south direction in the solar magnetospheric coordinates, maximized in March and September equinoxes. In the equinoctial hypothesis, the geomagnetic activity is at its maximum when the angle between Sun−Earth line (solar wind flux direction) and the geomagnetic dipole is 901, and lower in other epochs. This effect reduces the efficiency of solar wind – magnetosphere coupling during solstices. In the axial hypothesis, the peaks in geomagnetic activity occur when Earth is in higher heliolatitudes, where it is better aligned with any coronal mass ejection flux. Clu´ a de Gonzalez et al. (1993) have shown that the three effects are working together to produce the geomagnetic activity variation and they suggested that these mechanisms acting as modulators in the geomagnetic response for transient solar coronal mass ejections. Cliver et al. (2000), on the other hand, suggests that the equinoctial hypothesis explains in a better way the semiannual fluctuations than RM and axial mechanism. They have estimated that equinoctial mechanism is responsible for around 65% of the seasonal modulation whereas RM and axial have between 15% and 20% each in the modulation.

The annual periodicity (12-month periodicity) observed in the Sq, SD and SPMF is a reflection of the annual variation in geomagnetic activity. Annual variation is also known in solar wind (SW) speed, temperature and density (Bolton, 1990; Paularena et al., 1995; Szabo et al., 1996). Szabo et al. (1996) showed that annual variation in solar wind speed is strongest around solar minima. Zieger and Mursula (1998) have observed a very similar annual variation in solar wind speed and geomagnetic activity during the whole period of direct solar wind observations including the four solar minima before 1998.

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16 months periodicity observed in SPMF at BRW (71.3° N) and SJG (18.38° N); and SD at BNG (4.4° N), is quite similar to the 1.3 yrs periodicity observed by Paularena et al. (1995) which occurred concurrently in Solar Wind Speed and geomagnetic activity after 1987. Szabo et al. (1995) discovered the 1.3-year variation in the IMF north-south component. A strong, slightly longer periodicity of about 1.7 years (≈ 20.5 months) comparable with the 21-month periodicity found only in solar disturbance daily variation SD (see the 4th column of Table 2) was also found in cosmic rays during solar cycle 21 (Valdes-Galicia et al., 1996). Moreover, the 1.3-year periodicity has been observed in the variation of the solar rotation speed around the tachocline at the bottom of the solar convection layer (Howe et al., 2000). This observation gives additional importance for mid-term periodicities by suggesting that they are related to the variation of the solar dynamo and the emergence of magnetic flux. Valde's Galicia et al (2005) investigated the fluctuations in the total, open and closed solar magnetic flux (SMF) for the period 1971−1999 and found periodicities around 1.3 and 1.7 yr in the SMF with alternating importance during consecutive even and odd solar cycles. These fluctuations are directly related with variations present in cosmic rays, solar wind parameters and geomagnetic activity indexes. They asserted that it is through the magnetic flux that the solar dynamo influences several heliospheric phenomena.

Mursula and Zieger (2000, 2001) and Mursula et al. (2003) investigated the behaviour of the solar wind for several solar cycles and geomagnetic indices up to 15 solar cycles back in time. Their findings report the existence of variations with periodicities of around 1.3 and 1.7 yr in the analysed parameters that alternate in consecutive solar cycles since 1930, with the former dominating in even cycles and the latter appearing during odd cycles. More recently, Mursula and Vilppola (2004) investigated the behaviour of periodic variations in the solar wind and the IMF in the inner and outer heliosphere. They found that the 1.3 and 1.7-yr periodicities were present with different time behavior during solar cycles 21 and 22. More importantly the observed 1.3- and 1.7- yr periods in Sq, SD and SPMF are rooted in solar activity.

4.0. Conclusion

Investigation of the spectra associated with the H component of the geomagnetic field under quiet solar condition Sq, disturbed solar condition SD and superposed magnetic field SPMF using the data set that consists of hourly horizontal component H of the geomagnetic field intensity obtained simultaneously for the period 1996 through 2002 from seven observatories being coordinated by the INTERMAGNET network revealed the periods of 6 hours, 12 hours, 24 hours, 3 months, 6 months, 12 months and 16 months in the geomagnetic field components. These periods are associated with solar activities. This clearly shows the influence of an extra-terrestrial source (the Sun) on terrestrial processes. Sun is the undisputable driver of space weather.

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