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ASYMMETRY IN SEASONAL VARIATION OF GEOMAGNETIC ACTIVITY

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ABSTRACT

Seasonal variations in geomagnetic activities were studied for the period of 1990-2007 using Dst and AE indices. Over 150 events characterised by increase in geomagnetic activity of varying strength (from -90 up to -1800nT) were statistically analysed. Although Russell- McPherron effect plays a major role in the equinoctial asymmetry of the geomagnetic activity, others may also take place. During this study we found a statistically significant October-November peak in geomagnetic activity for Northern Hemisphere, which is sufficiently larger than March-April peak. Several hypotheses for the cause of such effect are discussed.

Keywords: Disturbance storm time (Dst), aurora electrojet (AE), seasonal variation, sunspots.

INTRODUCTION

When the Sun periodically experiences significant increase in sunspots and solar flare activity, flares release energy in many forms, including electromagnetic energy and energetic particles such as protons and electrons. When this energy reaches the Earth, it interacts with the Earth's magnetic field. This causes the visible phenomena of the northern or southern lights, it also generates an electric current that flows through the Earth's surface and can affect electric power, satellite communication, oil pipelines and human health. Several studies on geomagnetic variation have been established using different geomagnetic indices for geomagnetic activity at different latitudes: the high latitude include AE, AL, AU and AO (Lyatsky *et al*., 2001; Lyatsky and Hamza 2001; Lyatsky and Tan 2003; Ahn and Moon, 2003) aa, ap, Am for the mid latitude indices (Mayaud, 1980; Orlando *et al*., 1995; Schreiber, 1998; Clua de Gonzalez *et al*., 2001; Svalgaard, 2002) and low latitude Dst index (Takalo and Mursula, 2001; Hakkinen *et al*., 2003; Chen, 2004). Due to the different nature of the geomagnetic indices at different latitude their seasonal variation is also different (Ahn *et al*., 2000; Lyatsky and Tan, 2003). Many years ago three mechanisms were proposed to cause the seasonal variation of geomagnetic activity. Firstly, the axial hypothesis established the fact that the geomagnetic variation was associated with changes of the Earth heliographic latitude (+7.25^0 on 6 September and -7.25^0 on 5 March). This indicates that the Earth would be favourable connected to the solar wind from the active solar regions resulting in an increase in geomagnetic disturbance (Cortie, 1912). The second hypothesis is referred to as equinoctial hypothesis; it focuses on the angle when the dipole is perpendicular to the solar wind flow, increase in geomagnetic activity will occur at the equinoxes, March 21 and September 23 (McIntosh, 1959). Thirdly, Russell and McPherron's (1973) approach assumed that interplanetary magnetic field IMF lies in its typical parker spiral configuration on solar equatorial plane, the southward component of the interplanetary magnetic field in the geocentric solar magnetospheric (GSM) coordinate system is increased when the angle between the z axis of GSM coordinate and the solar equatorial plane is minimum near the equinoxes. The southward component of interplanetary magnetic field is maximum in early April and October.

Several suggestions were also raised as possible causes of diurnal and seasonal variations; recent result shows that ionospheric conductivity plays a crucial role in particle precipitation and substorm generation. Auroral and geomagnetic activities are associated with low ionospheric conductivity. When both auroral zones are in darkness, the conductivity in conjugate nightside auroral zones is minimum at equinoxes. Low ionospheric conductivity may be one of the major causes of the asymmetry in seasonal variation of geomagnetic activity (Lyatsky and Hamza, 2001).

Petrinic *et al*. (2000) using X-ray emission, suggested the occurrence between the daylight and darkness are interpreted as difference in the ionospheric conductivity, under the same condition consistently shows that intense auroral emissions are more likely when a given region is in darkness than when the same region is in daylight, this supports the idea that sunlight reduces the probability of establishing a large field line potential drop. Newell *et al*. (1996) also relates the frequent occurrence of electron acceleration in dark and sunlit conditions indicated by the solar zenith. It was observed that electron acceleration is

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common in darkness indicating that darkness is a factor for the field aligned potential drop to be produced.

Wang and Luhr (2007) observed that higher trigger level for substorm onsets exists when the conductance of the associated fluxtube connecting the magnetospheric source region to the ionosphere in both hemispheres is higher. From this, ionospheric conditions have a direct influence on the occurrence of a substorm. The lower Pedersen conductance of a fluxtube, the easier it is to initiate a substorm which are caused by solar illumination in the nightside auroral regions.

Clua de Gonzalez *et al*. (2001) argued that the causes of asymmetric variation of geomagnetic disturbance are still controversial. Takalo and Mursula (2001) observed that the variation of the Dst mainly comes from the effect of asymmetric ring current on the uneven distribution of the Dst stations. Hakkinen *et al*. (2003) established the fact when the sun rotates around different parts of its tilted magnetic field, Earth creating a sector structure in the IMF. In a tilted dipolar field, two sectors away from the sun and toward the Sun are observed. As the Earth is tilted along the direction of motion along its trajectory during the equinox, increase in geomagnetic activity is associated with the toward polarity of the IMF, which provides maximally anti parallel IMF fields with the geomagnetic dipole field. Similarly, geomagnetic activity is associated with away polarity of the IMF during the spring (Berthelier, 1976; Silverman, 1986). Campbell (1982) reported that the annual and semiannual variation changes that are observed in the Earth's heating and ionization during the yearly path around the Sun may be the causes of semiannual variation

All these mechanisms have contributed to the semiannual variation. Several studies Cliver *et al*. (2004), Temerin and Li (2002), O'Brien and Mc Pherrron (2002) agreed with earlier works (Mayaud, 1974, 1978; Berthelier, 1976; Svalgaard, 1977) that equinoctial hypothesis plays a major role as the principal cause of semiannual variation. Cliver *et al*. (2002) and Savlgaarg (2002) established the fact that equinoctial hypothesis account for 65- 75% of the amplitude of the six-month wave in the geomagnetic am index.

The purpose of this paper is to investigate the causes of seasonal and monthly variations of geomagnetic activity at different levels of Dst, AE indices and sunspot number.

Materials and Methods / Analysis

To demonstrate the effect of seasonal and monthly variations of geomagnetic activity the hourly mean values of Dst (Disturbance Storm-Time) index were designed to describe the axially symmetric variation of the geomagnetic field during the storms (Sugiura, 1964). Also in this study auroral electrojet index (AE) of hourly averages of the 2.5min values and sunspot number were employed.

The data for the years1990 to 2007 inclusive were obtained from Space Physics Interactive Data Resources (SPIDR) (http:// spidr.ngdc.noaa.gov, http://isgi.cetp.ipsl.fr/des_ae.html, http://swdcwww.kugi.kyoto-u.ac.jp/index.html), ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_NUMBERS/) except for the year 1996 for which AE index is not available online. The study herewith presented was based on statistical analysis of the distribution of events according to the levels of intensity of Dst and AE. The activity levels of the Dst binned in this study are as follows: -90nT to -130nT, -130 to -170nT, -170nT to -210nT, -210nT -500nT. On the other hand, the activity levels of the AE index are: 0nT to 400nT, 400nT to 800nT, 800nT to 1800nT.

The seasonal periods used in this study are centred on each Winter, Summer, Spring and Autumn, and are defined by the day of the year. Winter is defined as 22nd December 22nd March, Spring is defined as 22nd March 22nd June, Summer is 22nd June 22nd September, and Autumn is 22nd September 22nd December.

Figure 1 shows, the activity level of 90nT - 130nT, 80 moderate storms with maximum number of occurrence (33.8%) were recorded in Autumn with another peak in Spring (25%), while the least occurrence (18.8%) was recorded in Winter. The activity level of 130nT - 170nT has 45 intense storm with maximum numbers (28.8%) recorded in Autumn and with another peak values in Spring (26.6%), while the least number of occurrences (20%) was in Summer. For the activity level of 170nT-210nT, 19 more intense storms were obtained with maximum number (42.1%) recorded in Autumn with another peak values in Spring and Summer (21%), while the least number of occurrences (15.7%) was in Winter.

For the activity level of 210nT-500nT, 24 most intense storms (severe) with maximum number (62.5%) were recorded in Autumn with another peak in Spring (25%) with least number of occurrences (1%) occurring in Winter.

A similar statistical analysis was also performed in figure 2 for AE index which indicates that the largest occurrence events in the threshold are in Autumn from 0 to 400nT, 400nT to 800nT except 800nT and above which shows large occurrence events in Summer. From the overall view of the AE distributions, it was observed that Autumn have the highest threshold from 0 to 1800nT with 56 events, with another peak in Spring of 40 events.

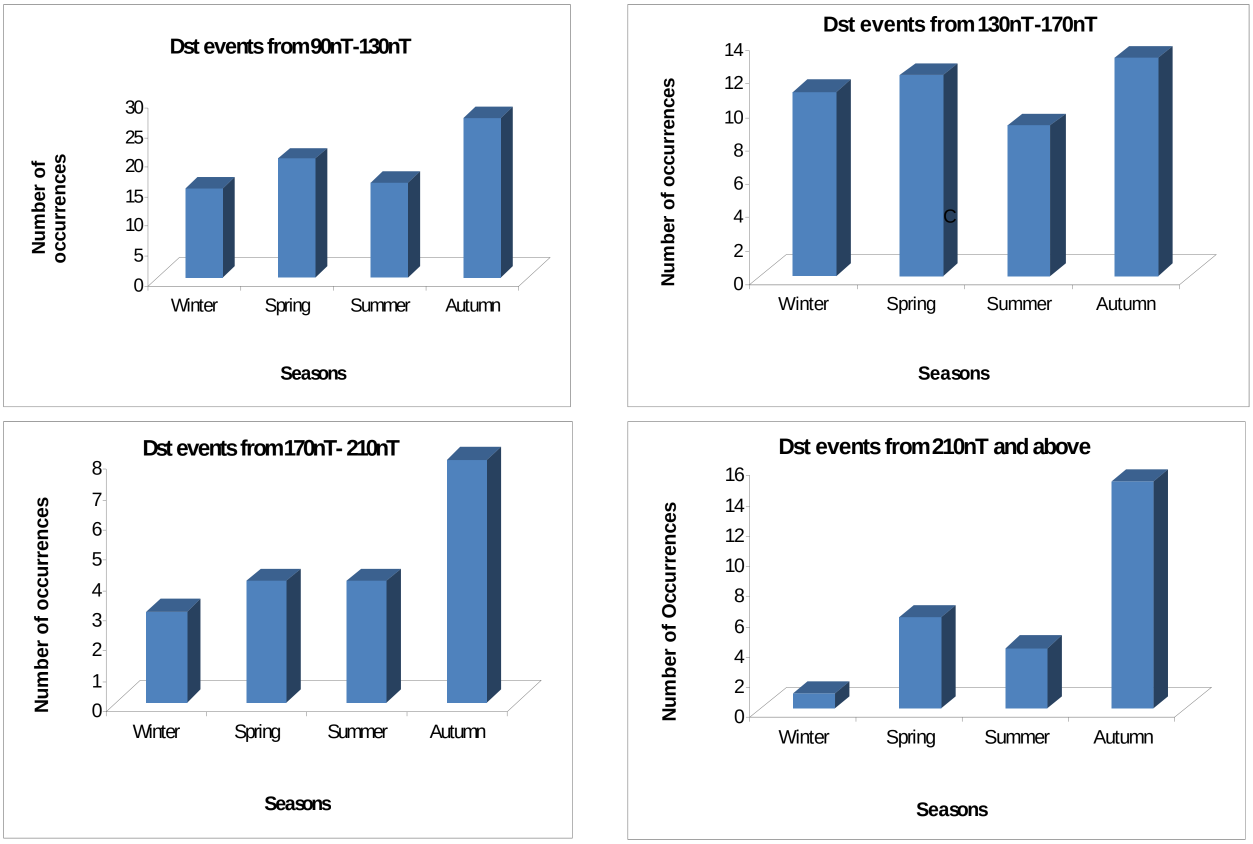

Fig. 1. Seasonal variation of disturbance storm time at different activity level of (from top to bottom) 90nT-130nT, 130nT-170nT, 170nT-210nT and 210nT above for the interval 1990-2007.

Also activity levels of the Dst that binned in this study were used to examine the sunspot number around the dates events between 1990-2007 (Fig. 3). Between the activity levels of 90nT-130nT maximum number of sunspot was recorded in Autumn (33.67%) with another occurrence in Summer (31.16%) and low value of sunspot in Winter and Spring (19.32% and 15.40%) At the activity levels of 130nT- 170nT Autumn has the highest values of sunspot 41.75%, winter 27.38%, Spring 18.22% and Summer 12.65%. It was also recorded that Autumn has the highest number of sunspot 40.33%, Spring 23.97%, and Summer 23.60% and12.10%. At 210nT and above, the number of sunspot was also high in Autumn 46%, Spring 37.70%, Summer 9.75% and Winter 5.55%. Figure 4 shows the monthly average values of sunspot number, it indicated maximum occurrence of sunspot number in October with another increase in November.

There is need to examine the influence of solar activity on Dst, and AE indices which led to the plotting of Dst, AE and Sunspot number R. The plotting has trend line equations:

$$D_{st} = 13.955 + 0.0426AE + 0.834R \quad (1)$$

$$AE = 60.502 + 14.306R \quad (2)$$

$$Dst = 16.532 + 1.443R \quad (3)$$

In equation (1), multiple regressions analyses were performed between Dst, AE and sunspot number R with correlation coefficient and coefficient of determination of 0.929 and 0.863. Also auroral electrojet were plotted against sunspot with correlation coefficient and correlation of determination of 0.824 and 0.679 in equation (2). Equation (3) shows the relationship between Dst and sunspot with high correlation coefficient and correlation of determination of 0.892 and 0.796 (Fig. 5).

RESULTS AND DISCUSSION

Semiannual variation of Dst and AE

From the analysis, it was clearly revealed that the Dst and AE indices undergoes a semiannual variation which is peak during Autumn at all the activity levels with another increase in Spring (Figures 1 and 2). The occurrence rate of large geomagnetic storms displays a pronounced

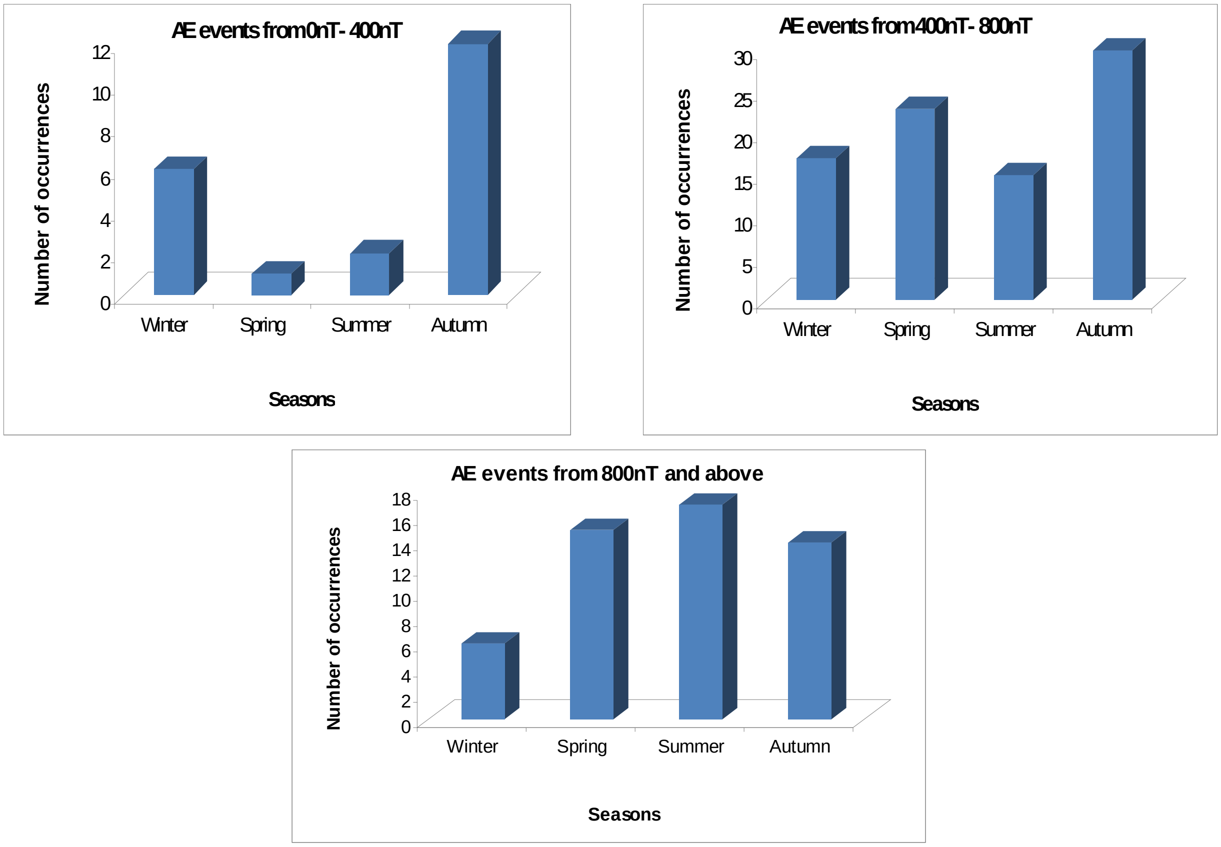

Fig. 2. Seasonal variation of geomagnetic activity at different activity level of 0-400nT, 400nT-800nT and 800nT above using auroral electrojet.

semiannual variation. Russell-McPherron RM effect suggested that the geoeffectiveness of the causative eruptive solar events have a seasonal dependence. The result shows that 37.5% of geomagnetic activity occurs during the Autumn (October and November) and only 25% of geomagnetic activity occurs during Spring (March- April).

Asymmetry variation of geomagnetic activity is clearly visible in figures 1 and 2, it suggests that the semiannual variation is enhanced in auroral zone (Lyatski and Tan, 2003) which affect everyday amplitude of the diurnal variation. Therefore, aurora electrojets are primary currents affected by storm and substorms, enhanced the diurnal and semiannual variation around equinoxes, even when geomagnetic activity is low (Chulliat *et al*., 2005).

Different researchers have monitored the drivers of seasonal variation of geomagnetic activity using both Dst and AE indices (Burton *et al*., 1975; Cliver *et al*., 2000). Our result indicates that the RM effect is more significant than axial and equinoctial effect. We conclude that during geomagnetic storm, many storms occur during the October/November month implying that 50% energy is injected per storm during the Autumn than Spring.

We observed the greatest occurrence of geomagnetic activities during the period of the Autumn and Spring seasons. Both seasons have greater occurrence probabilities than Winter and Summer seasons, which could be related to ionospheric conductivity and RM effect as an important influencing factor of southward component B_z of the IMF in the GSM system, which largely controls both the semiannual and the diurnal modulation of the geomagnetic activity. If B_z has a negative value in GSM (Geocentric Solar Magnetospheric System) then substantial energy can be transferred into the terrestrial environment through magnetic field line interconnection than by zero or positive B_z. The RM effect implies that GSM Bz is projected (sunward) GSE B_y during Spring and positive (outward) GSE B_y during Autumn. Baranyi and Ludmany (2005) emphasized that substantial negative occurs in two ways; IMF B_z component has a significant negative value in the GSE

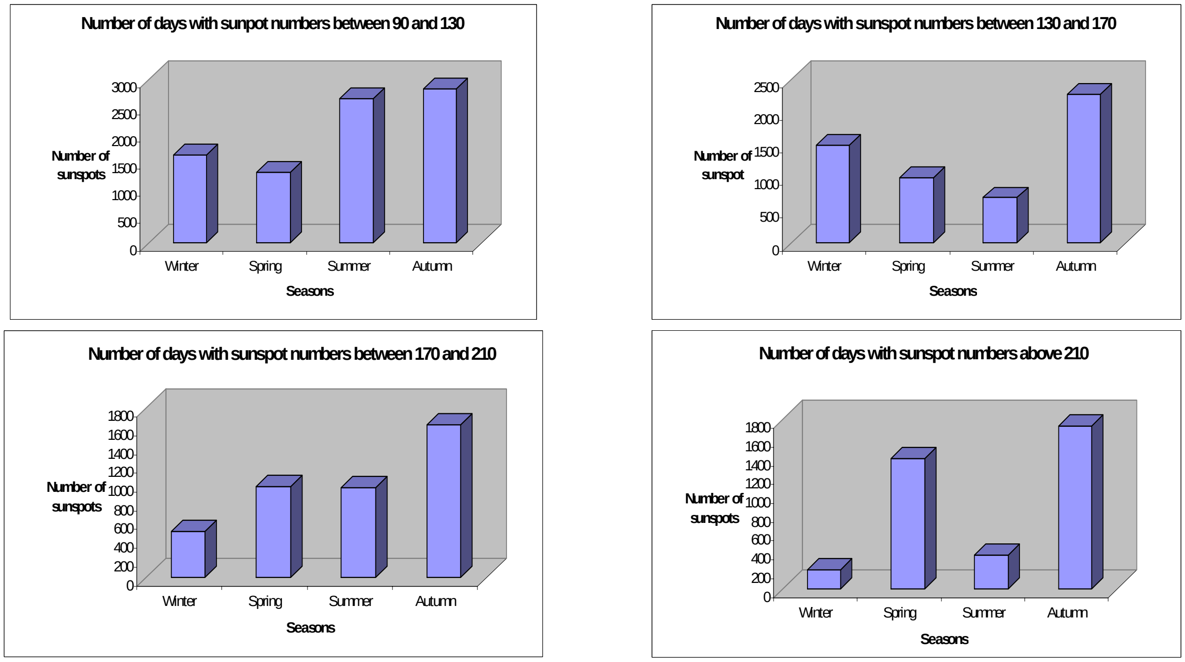

Fig. 3. Seasonal variation of geomagnetic activity at different activity level of (from top to bottom) 90-130nT, 130-170nT, 170-210nT and 210nT above for the interval 1990-2007.

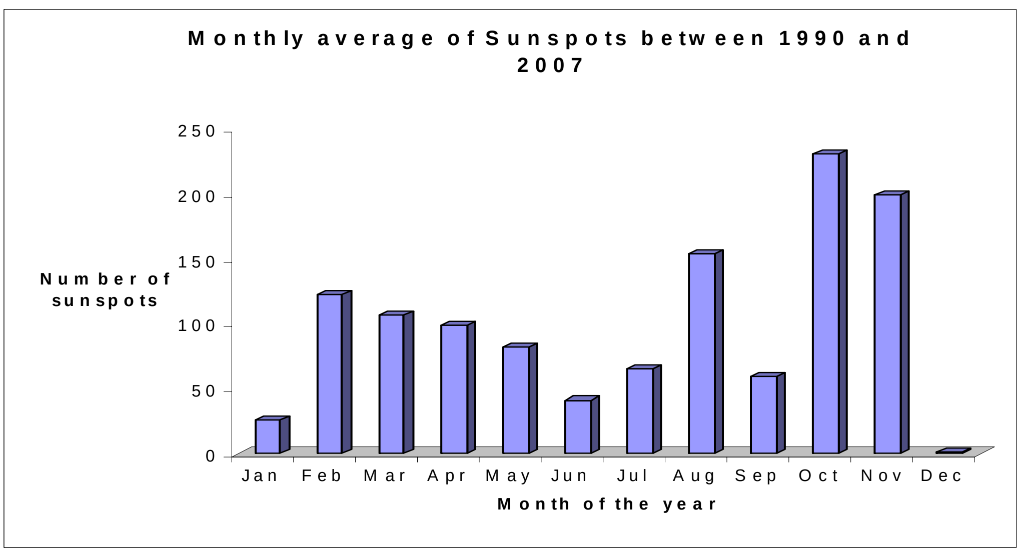

Fig. 4. Monthly average geomagnetic activity from 1990-2007 using sunspots number.

(Geocentric Solar Ecliptic System) which does not vanish in the GSM, and the GSE B_y component projects negative B_z component into the GSM. Cliver *et al*. (2004) emphasised that Russell- Mc Pherron effect was enhanced by Rosenberg- Coleman polarity effect (an axial polarity effect) which increase the amount of negative (toward the sun) and positive (away from the sun) polar field observed during the first and second half of the year, such field yield a southward component in GSM coordinate under Russell- Mc Pherron effect.

However, there is a peak occurrence of geomagnetic storm for the month of October and November with 37.5% of all substorm occurrences, while only 25% of geomagnetic storms occur for the month of March and April. Thus, there is a 50% increase of the storm activity compared to the Spring season (March and April).

Crooker and Siscoe (1986) and Cliver *et al*. (2000) explained the semiannual variation in which the Bz coupling efficiency between the solar wind and

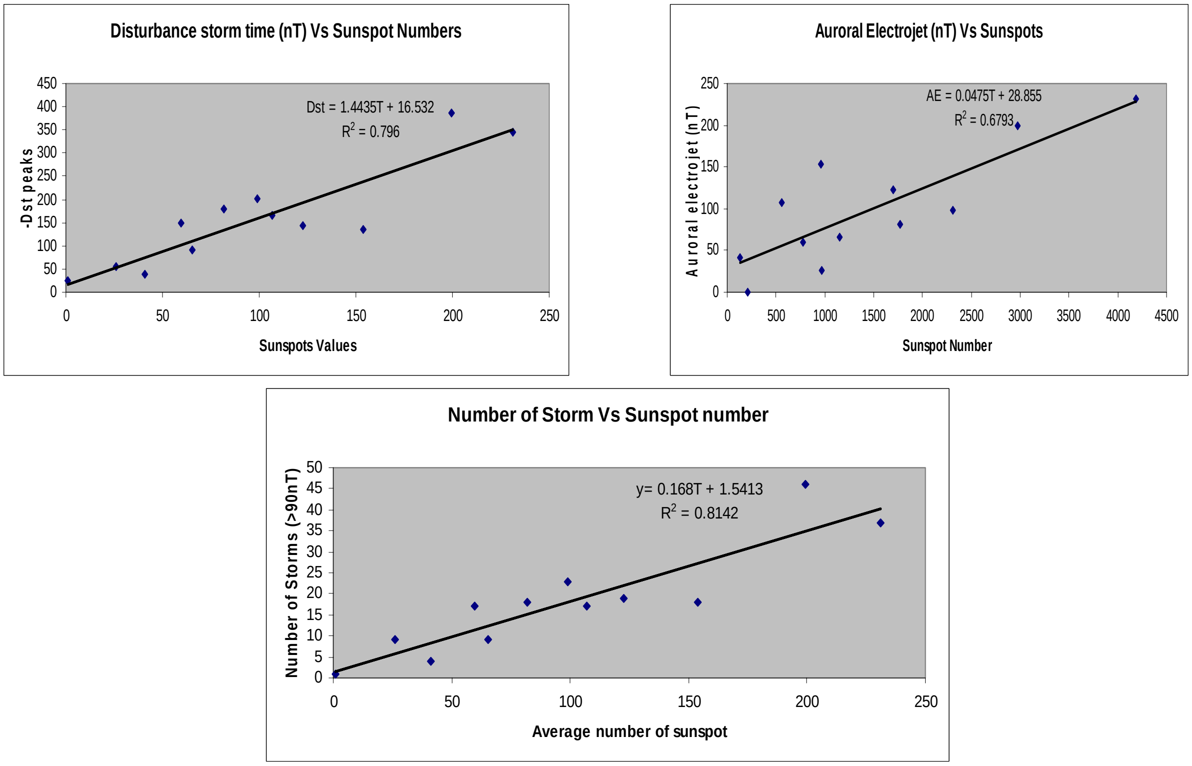

Fig. 5. The scatter plot of Dst index values against sunspot values (first panel), auroral electrojet against sunspots number (second panel) and number of storm exceed 90nT against average number of sunspot (third panel) from 1990-2007. The correlations are statistically significant, which appear to be directly related to geomagnetic disturbance.

magnetosphere can be modulated by the tilt angle of Earth dipole. Mc Pherron (2000) determined that the coefficients in the Burton *et al*. (1975) equation, which relates to changes in the Dst to solar wind parameters are dependent on the tilt angle. Olson (1970) suggested that magnetopause current, ring current and field current have effect on Dst index, and changing direction between the solar wind flow direction and Earth dipole axis may have effect on all the currents. This implies that the dayside reconnection process between the interplanetary magnetic field and geomagnetic field may cause asymmetry variation in geomagnetic activity.

During Autumn and Spring seasons enhancement in magnetic activity is expected according to Russell - McPherron (1973). It was observed from our analysis that nightside and early morning has higher occurrence frequency for substorms from 1990-2007. No significant substorms occurrence was observed in mid noon. Therefore solar zenith angle is the key factor controlling the ionospheric conductivity. Large numbers of low energy electron move along the field to serve as charge carrier created by ionizing UV. When one nightside auroral is sunlit current flows smoothly and is stable, on the other side when no conducting path exists resulting to no charge carrier sufficient through impactation of ionization of the upper atmosphere then ionospheric conductivity is enhanced resulting to higher current, more auroral and more explosive discharge occur, geomagnetic activity will be maximal when the nightside auroral oval is in darkness even in more sunlit hemisphere (Lyatsky *et al*., 2001). This implies that ionospheric conditions also have a direct influence on the occurrence of a substorm.

Regression analysis of Dst, AE and Solar activity

From our analysis, the result confirms that sunspot activity is one of the main sources of geomagnetic activity. The equation (1) correlation coefficient is 0.929 between the fluctuation of Dst, AE and sunspot activity which confirms the direct relationship between the Dst, AE and solar activity. The coefficients of determination of 0.863, implies that 86.3% of the total variation in Dst and AE indices can be solely accounted for by sunspot activity. Also equation (2) with correlation coefficient of 0.824 and coefficients of determination of 0.679, which signifies that 67.9% of AE can be accounted for using sunspot activity. In equation (3), correlation coefficient 0.892 with correlation of determination 0.796, implies that 79.6% of Dst can be accounted for using solar activity. There is also good correlation between number of storm and sunspot number with high correlation coefficient of 0.9023 and coefficient of determination of

0.814, implying that 81.4% of geomagnetic activity can be accounted for using number of storms and sunspot number (Fig. 5). Feyman (1982) noted that as the sunspot number increases the level of geomagnetic activity increases as well, this implies that level of geomagnetic activity is proportional to the sunspot number.

Legrand and Simson (1991) studied the topology of solar coronal field and showed that geomagnetic activity as presented by SSC storm disturbed random is linked to sunspot activity while recurrent storm is associated with corotating high speed solar wind streams. Thompson (1993) also considered that the contribution to geomagnetic disturbance is linked with solar maximum. It is reasonable to expect that occurrence of different levels of geomagnetic activity during the maxima phase of a solar cycle can be directly related to the maximum sunspot. Figure 5 shows that a linear relationship exists between occurrence frequencies of different levels of Dst, AE indices added together for seventeen years centred on sunspot number. The correlation coefficient and coefficient of determination are significant in this study.

CONCLUSION

The seasonal and monthly variation of the AE and Dst indices were presented. From the study, the statistical analysis shows the geomagnetic activity distributions corresponding to geomagnetic storms in the range of moderate to intense level of intensity. During this study we found a statistically significant October-November peak in geomagnetic activity for Northern Hemisphere, which is sufficiently larger (by 50%) than March-April peak. As a consequence, this asymmetric variation may be in agreement with well-known recurrent geomagnetic activity patterns explicable by annual and semiannual changes in the Earth's heating and ionization during the yearly path around the Sun; and could also be related to deposition of energy in one of the auroral zones, mostly at the Autumn and Spring. It reasonable to expect that occurrence of different levels of geomagnetic activity during the maxima phase of a solar cycle can be directly related to the maximum sunspot. There is a significant relationship between the sunspot number, Dst and AE indices. The IMF-effect which increases the solar wind-magnetosphere interaction might also cause more geomagnetic activity during Autumn and Spring, also when the Earth is favourably connected to the solar wind from the active solar regions as equinoctial increase in solar wind speed. Ionospheric conditions may also have a direct influence on the occurrence of a substorm, the lower Pedersen conductance of a fluxtube the easier it is to initiate a substorm. The asymmetry variation of geomagnetic activity implies that there is an increase in the energy input in the magnetosphere due to the solar wind –magnetosphere interaction.

Our results are important from space weather effect and prediction point of view. Knowing that storm occurrence is generally much higher during the Autumnal asymmetry (October- November), this study provides the scientific community with the information about the asymmetric variation of geomagnetic activity and its implication to space weather study.

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