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Semi-Annual Variation of Geomagnetic Indices for the Period of 1970-2009

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Semi-Annual Variation of Geomagnetic Indices for the Period of 1970-2009

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Abstract - Semiannual variations of the geomagnetic disturbances for different geomagnetic activity indices exhibit distinct characteristics for the period of 1970-2009. In this paper, the semiannual variation of geomagnetic activity is significant in the low-latitudinal Dst index showing the magnitude of the ring current, less significant in the midlatitude of Ap and Kp indices. There is no evidence of semiannual variation in the auroral electrojet AE index but clearly observed in AL index which are measure of global geomagnetic activity in the auroral zone, also responds to convection electrojets and substorms electrojet. The correlation coefficient was used to determine the reliability of the variation, which ranges between 0.595-0.988.

I. Introduction

The use geomagnetic activity indices (AE, AL, AU, AO, Dst, Kp, aa, ap) and solar activities (Sunspot number and Solar flux 10.7) plays an important role in the study of geomagnetic disturbance variation. The geomagnetic activity indices are used for measuring the level of geomagnetic activity. These indices are computed from measurements of geomagnetic disturbances. Semiannual variation of geomagnetic disturbance has been studied using different indices, the aa, Ap, and Am midlatitude indices (for example, McIntosh, 1959; Russell and McPherron, 1973; Bertelier, 1976; Mayaud, 1980; Orlando et al., 1993; Cliver et al., 2000, 2002), low-latitude Dst index (Cliver et al., 2000; Chen 2004; Falayi and Beloff, 2009) and auroral electrojet AE, AL, AU, and AO indices (Bertelier, 1976; Hajkowicz, 1998; Ahn et al., 2000; Cliver et al., 2000; Lyatsky et al., 2001; Benkevitch et al., 2002).

Traditionally, these variations have been attributed to three external effects: Changes in the heliographic latitude of the Earth during the year (Cortie, 1912); variations of the solar wind flow direction with respect to the Earth’s magnetic dipole axis (Bartels, 1925; McIntosh, 1959); and variation of the angle between the geocentric solar magnetospheric (GSM) equatorial plane and the solar equatorial plane (Russell and McPherron, 1973). The Earth reaches extreme heliographic latitudes near equinoxes which lead to enhanced geomagnetic activity during those periods, as the Earth is then better connected to the fast solar wind streams from the low-latitude coronal holes. Annual variation is also known in solar wind (SW) speed, temperature and density (Bolton, 1990 and Paularena et al., 1995). Szabo et al. (1995) established that annual variation in speed is strongest around solar minima.

The general tendency for magnetic disturbances to be stormier at equinoxes than at solstices has been recognised for more than 150 years (Sabine, 1856) and the cause of the semi-annual variation has been studied by many researchers (Lyatsky and Hamza, 2001; Lyatsky and Tan, 2003; Byung-Ho and Ga-Hee, 2003; Clua de Gozalez et al., 2001) and its cause remain under discussion in the scientific community. Statistical studies by Ahn et al. (2000), and Lyatsky et al. (2001), demonstrated strong differences in the seasonal variations for various geomagnetic activity indices and the strong dependence of these variations with latitude. Regression analysis shows that the majority of seasonal variability is attributed to a generalized equinoctial effect, the geomagnetic activity correlates well with the angle between the Earth's dipole axis and the Earth-Sun line (Orlando et al, 1995; Cliver et al., 2000). Because the Earth's magnetic dipole axis is offset from the spin axis, the angle the dipole makes with the solar wind varies over the course of a day. Crooker and Siscoe (1986) explained the semiannual variation in which the Bz coupling efficiency between the solar wind and magnetosphere can be modulated by the tilt angle of Earth dipole. Falayi and Beloff (2009), found a statistically significant in October-November peak in geomagnetic activity for Northern Hemisphere, which is sufficiently larger (by 50%) than March-April peak.

In this paper, we study the long-term evolution of the semiannual variation using early geomagnetic activity. Here we use this correlation to study the annual mean variation of geomagnetic activity. Dst (Disturbance Storm Time), Kp, Ap, AL, AE indices, solar flux and sunspots are key features in the forecast of geomagnetic activity.

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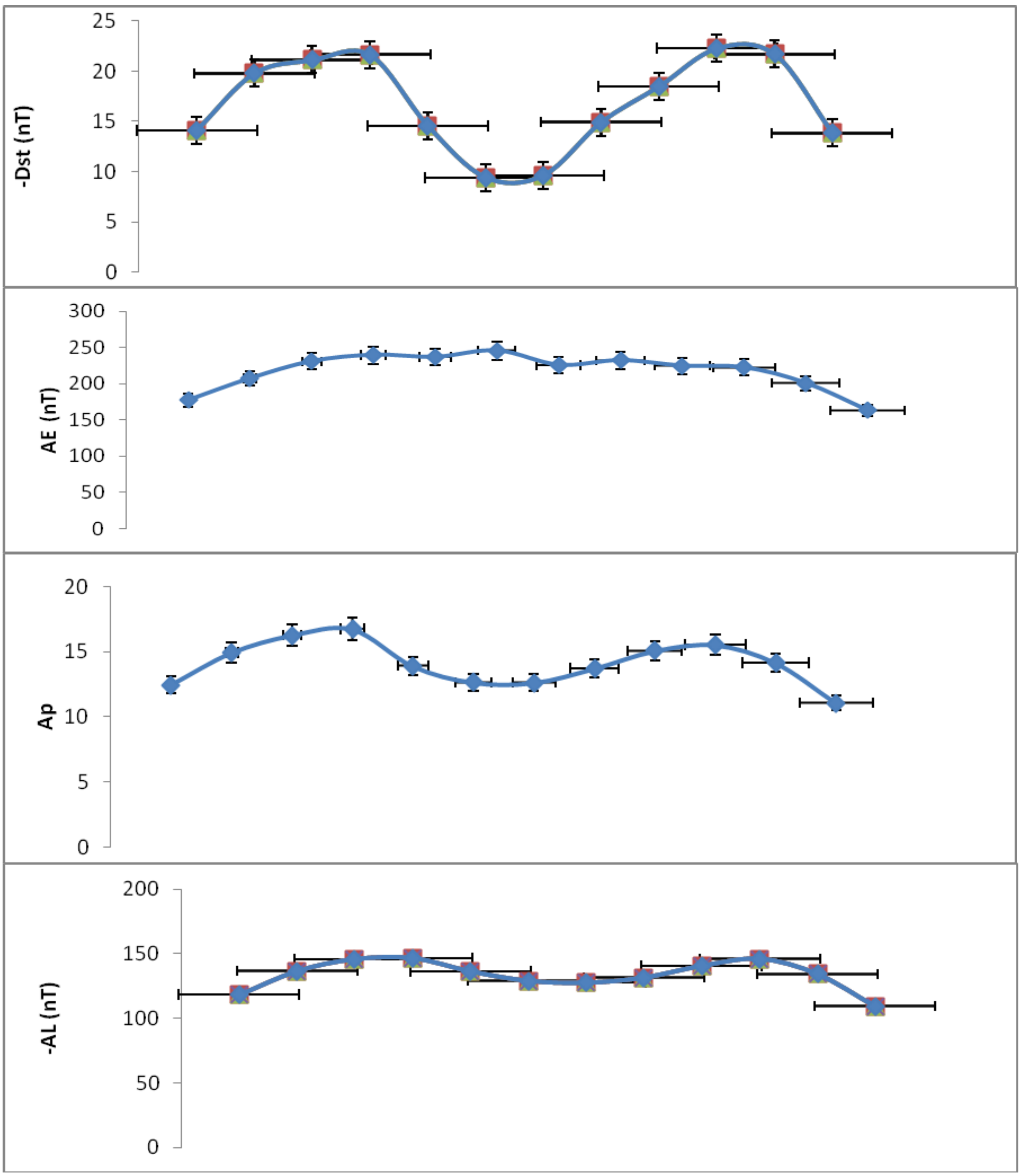
II. Data Analysis

a) *Annual Variation For Geomagnetic Activity Indices*

Figure 1 demonstrated the semi-annual variation in the monthly mean of the low latitudinal Dst index, two midlatitude Ap and Kp indices and AL (negative component of the auroral electrojet) for the period of 40 years from 1970-2009. We took the data from (http://omniweb.gsfc.nasa.gov). Since the Dst index is commonly negative, for better comparison with other indices the absolute values of the Dst index are shown. We computed monthly average of the indices for periods shown in Figure 1. It also demonstrated the semiannual variation of geomagnetic activity is significant in the low-latitudinal Dst index showing the magnitude of the ring current. The AL index, which is the negative component of the auroral electrojet index AE, is utilized to study the universal time seasonal variations of northern hemisphere auroral zone magnetic activity in the midnight sector on quiet days. There is no evidence of semiannual variation in the auroral electrojet AE index which is a measure of global geomagnetic activity in the auroral zone, also responds to convection electrojets and substorms electrojet. It less significant in the midlatitude of Ap and Kp indices, which show magnetic disturbances at middle latitudes propagating there predominantly from higher latitudes.



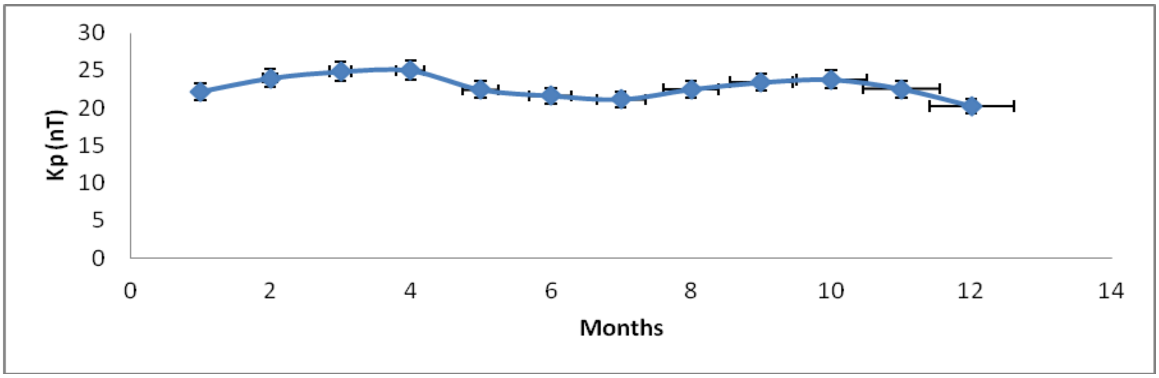


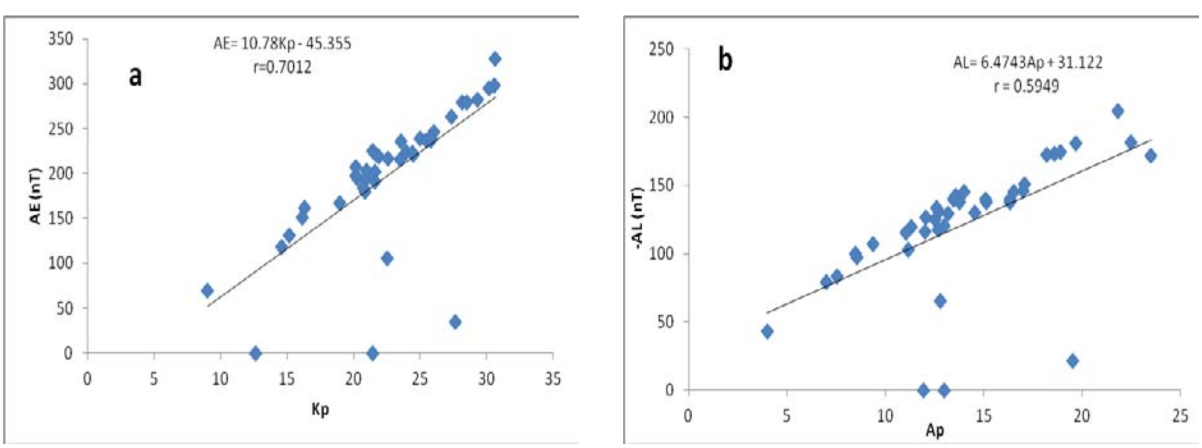
Figure 1. Monthly average variations of Dst, AL, AE, Kp and Ap indices from 1990-2009.

b) Annual Correlations

In order to make evident of the annual trend of the geomagnetic activity, averaging together corresponding monthly values of Dst, AL, AE, Kp, Ap, Rz and Solar flux 10.7 over the whole period considered (1970- 2009). The method to determine the reliability of the obtained variations is the correlation coefficient (r). From Figure 2 we show the values of the indices and the straight lines of best fit given by the linear regressions which shows a strong correlation was established between annual mean of AL versus Ap and AE versus Kp (see Figure 2 a and b). The correlation coefficient between annual mean of AL versus Ap and AE versus Kp ranges between 0.595 and 0.701 respectively. Correlation over the entire period is strong but not as strong as for an individual storm. However, the correlation for AE versus Kp is high, as they monitor similar ionospheric currents and have their geomagnetic stations fairly close.

The good correlation is a validation of the idea that sunspot number is a good proxy for solar flux 10.7. There is a strong positive correlation (correlation coefficient 0.988) between the two quantities (Figure 2c). Also Figure 2 (d-f) shows Dst versus Ap, sunspot number and solar flux with correlation coefficient of 0.783, 0.643 and 0.651 respectively. Dst index shows a state level of geomagnetic activity and is basically connected to the geomagnetic field near the equator and to the condition of the ring current, and it describes the development of global large scale of geomagnetic disturbances. The result indicated that Ap and Dst indices are potentially useful in prediction of storm time enhancements of ring current intensity.

Feynmann (1982) had noted that as the sunspot number increases the base level of geomagnetic activity increases as well, this determine the level of geomagnetic activity which is proportional to the sunspot number. Sunspot number R_z is commonly considered an appropriate and reliable index of solar variability. Variations of solar activity and prediction of its change on both a short- and long-term basis is becoming increasingly relevant because of our improving knowledge of the Sun-Earth relationships and the influence of solar activity on geomagnetic variations.



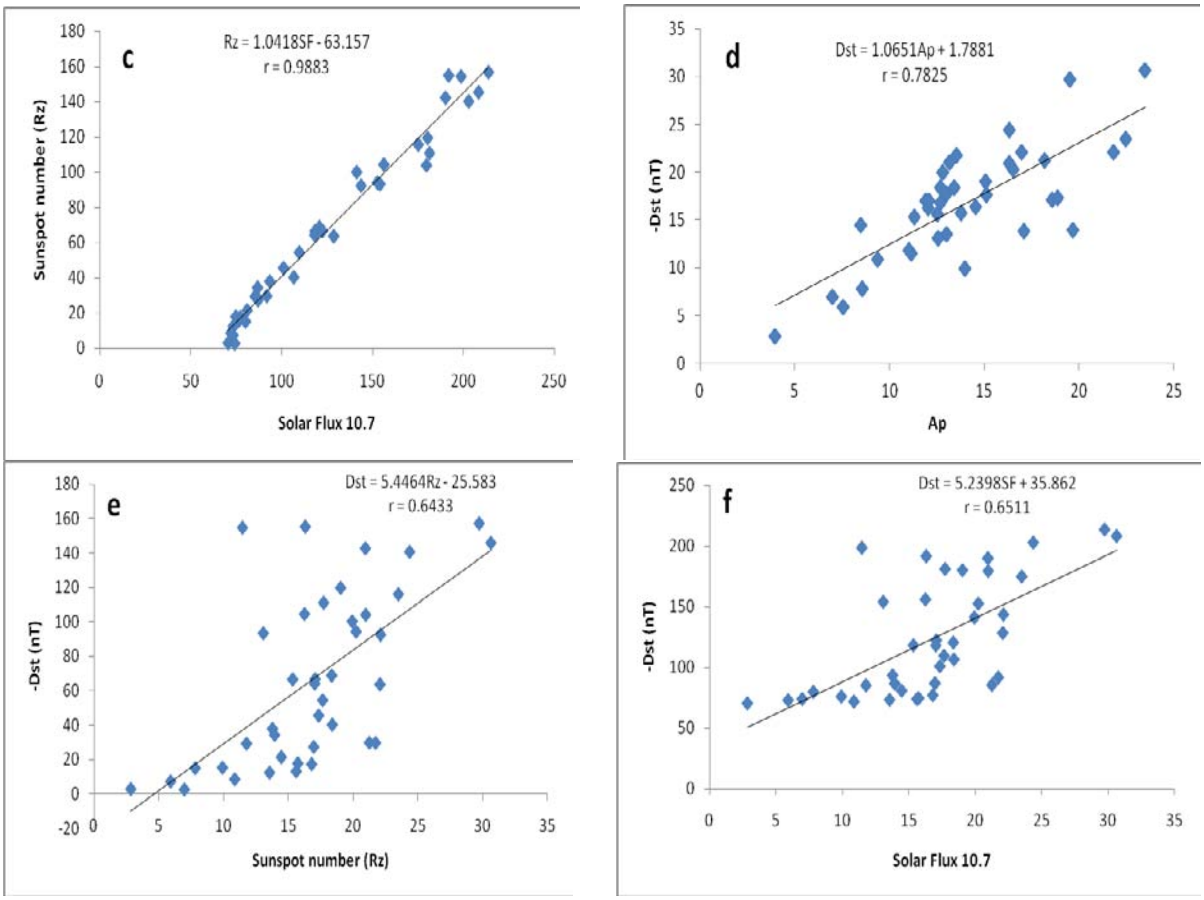


Figure 2. Correlation plots for annual mean AE, AL, Dst, Kp, Ap, Sunspot number and Solar flux.

(a) (b)

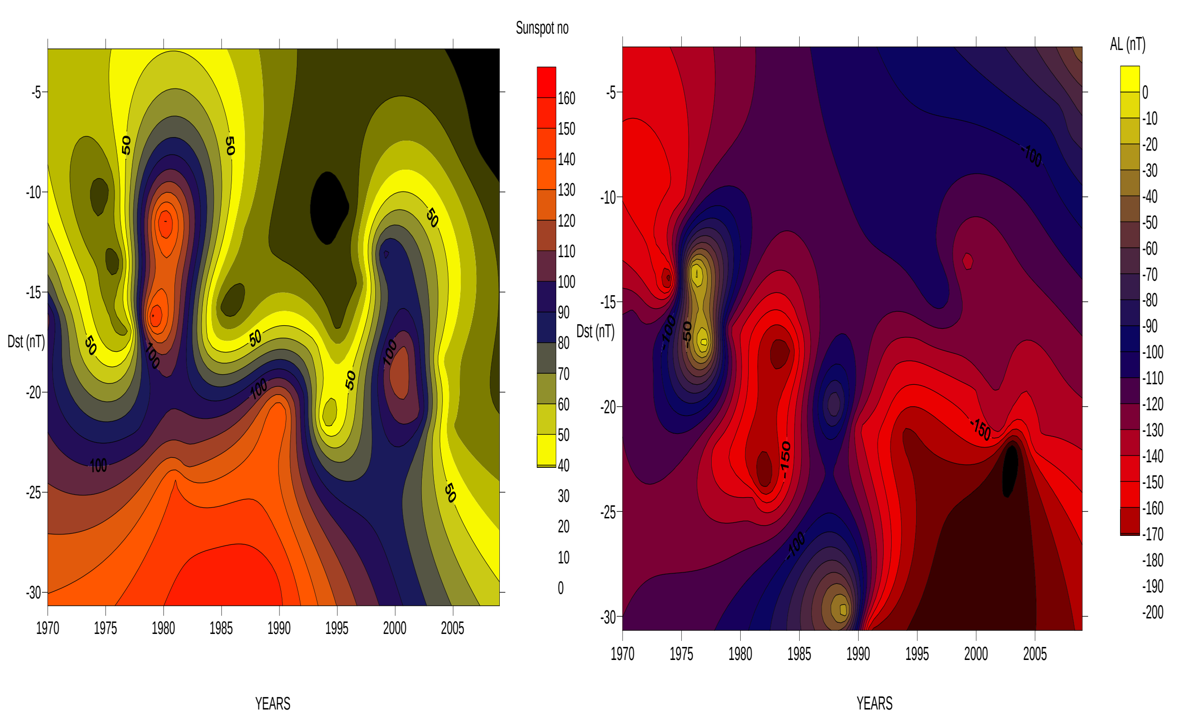


Figure 3. Annual variation of geomagnetic activity predicted from a) Dst and Sunspot number b) Dst and AL.

Figure 3 show the contour plot of annual variation of Dst index, Sunspot number and AL index, It was noticed that each of the effects produces distinct annual variability patterns and hence their contribution could be identifiable from the data. The contribution to the annual variations from the ring current at low latitude appears statistically comparable with the contribution from sunspot number and substorm westward electrojet at high latitudes. The annual variation was observed between the years of 1970-2009, may be caused by unsymmetrical geomagnetic disturbances between hemispheres. The annual variations may be as results of the high speed of solar winds are transported inward to the ring current region during magnetic storms. This accumulated energy is indicated by westward electrojets, which contribute to AL, making it more responsive to the reconnection in put on the time scales considered (Figure 3b). This produces a diamagnetic decrease in the Earth's magnetic field measured at near-equatorial stations, and is the cause of the main phase of the magnetic storms (Lyatsky and Tan, 2003).

III. Results And Discussion

The result reported here gives support to Russell and McPherron model. From Figure 1 we observed the greatest occurrence of geomagnetic activities during the period of the April and October. This is an evident that the interplanetary magnetic field (IMF) is a significant factor for geomagnetic activity. The south component *Bz* of the interplanetary magnetic field is always associated with the progress of the magnetic field reconnection at the magnetopause. However, the energy of the solar wind is input into the magnetosphere, driving drastic geomagnetic disturbances such as geomagnetic storm and substorm. The geomagnetic activity has long been known to be highly variable in time. One of the earliest variations distinguished in the geomagnetic activity were its semiannual variation. 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.

The semiannual variation is clearly observed in the AL index showing substorm activity while the AE index shows no semiannual variation in the study. The analysis has shown that when corrections are made for the solar zenith angle variation with month, the seasonal variation of electrojet current maximises during equinoctial months. This result may testify the important role of conjugate auroral zone conductivity in substorm generation, which has a clear semiannual variation as discussed by Lyatsky et al. (2001), Benkevitch et al. (2002) and Newell et al. (2002). The observed features of the semiannual variations may be caused by two main sources of geomagnetic activity, increases in the ring current and substorm westward electrojet during enhanced geomagnetic activity around equinoctial months (Figure 1).

Semiannual variation of geomagnetic activity to be very strong in the low-latitudinal Dst index showing the magnitude of the ring current. Such variation with a lesser amplitude is also seen in the midlatitude Ap and Kp indices, which show magnetic disturbances at middle latitudes propagating there predominantly from higher latitudes. The seasonal variations in geomagnetic activity indices showed that the study of auroral electrojet AE and AL indices showed that the semiannual variation is evident in AL index but not observed in AE index.

In this study, we investigated linkage between the geomagnetic indices and solar activities, the correlation coefficient for the relation tested; these had values ranging from 0.594-0.988 for correlation coefficient (Figure 2). From our analysis, the result confirms that sunspot activity is one of the main sources of geomagnetic activity. This variation may be strongly influenced by the strength and direction of the interplanetary magnetic field and by the solar-wind velocity, density, temperature and kinetic energy. The surface signature of the solar wind magnetosphere interaction manifests itself differently in the auroral zones, mid and low latitudes. Observing the correlation between solar activity (sunspot number and solar flux 10.7) and the geomagnetic activity index (Dst), we found a decrease in the correlation between the two parameters in the current in Figure 2 (e and f). The variability in geomagnetic activity may be as a result of solar wind emanating from polar coronal holes.

Despite the observational support, the way the equinoctial mechanism works has remained unknown (Cliver et al., 2000). Boller and Stolov (1970) suggested a theoretical explanation of the equinoctial effect in terms of the Kelvin-Helmholtz's instability. They proposed that annual and diurnal variations of the Earth's dipole to the solar wind cause modulations of the conditions favourable for the development of Kelvin-Helmholtz's instability at the flanks of the magnetosphere. 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.

We found that AL shows semiannual variation pattern, suggesting that the electric field is the main modulator of the semiannual magnetic variation. Also AL currents have a more rapid response to the IMF direction than the AU currents (Nowada et al., 2009). The Dst index was found to show more prominent seasonal variation than the AE indices, therefore variation of the Dst index is noticeable during the main phase of a magnetic storm.

IV. Conclusion

In this paper, we analysed monthly means for the period 1970 to 2010 in order to highlight the annual and semi-annual variations. The mechanisms causing these variations are complicated and still an open issue. The semi-annual peak is clearly better detected DST and AL; this is related to Russell-McPherron effect (Russell and McPherron, 1973). The semiannual variation of geomagnetic activity implies that there is an increase in the energy input in the magnetosphere due to the solar wind-magnetosphere interaction. The dayside reconnection process between the interplanetary magnetic field and geomagnetic field may cause asymmetric variation in geomagnetic activity. In this study we also showed annual variation of geomagnetic indices.

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