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Dependence of the Spring-Autumnal asymmetry in geomagnetic activity on the solar main dipole magnetic field polarity over last 140 years

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ABSTRACT

Spring-Autumnal asymmetry (SA asymmetry) from years 1873–2010 in the geomagnetic activity is investigated based on the geomagnetic indices (aa, Ap and Kp). Results have shown that in general the SA asymmetry of the geomagnetic activity appears to be alternation, except for the interval during which the change of dominant solar dipole magnetic field polarity occurs. Our study implies that both the polarity of the main solar dipole field and the north-south asymmetry of the sunspot area in the two solar hemispheres control the strength of the south component (*Bs*) of the interplanetary magnetic field (IMF) near the Earth and the resulting SA asymmetry of the geomagnetic activity in the corresponding seasons. A simple sector structure model is devised to establish the relationship between the polarity of solar main dipole magnetic field, the IMF *Bs* component and the corresponding SA asymmetry in the geomagnetic activity. This is confirmed by examining the solar wind parameters from the spacecraft observations during the recent decades.

1. Introduction

It has been studied for decades that there is a semiannual variation with maxima at equinoxes and minima at solstices (Sabine, 1856; Cortie, 1912; Chapman and Bartels, 1940; Russell and McPherron, 1973; Gonzalez et al., 1993; Cliver et al., 2000). There are several mechanisms which can account for the semiannual variation in the geomagnetic activity. The axial mechanism is established on the fact that geomagnetic activity is associated with the variation of the Earth heliographic latitude, which reaches its maximum heliographic latitude of $+7.2^{\circ}$ and -7.2° on approximately September 6 and March 5, respectively (Cortie, 1912; Priester and Cattani, 1962). The equinoctial mechanism is focused on the interaction between the solar wind and the Earth's magnetosphere with orientation of the Earth's magnetic dipole relative to the Sun- Earth line, namely the dipole tilt angle effect, which predicts geomagnetic activity maxima at equinoxes, March 21 and September 23 (McIntosh, 1959; Bartels, 1963). The Russell-McPherron mechanism is attributed to the southward Interplanetary Magnetic Field (IMF) component in the Geocentric Solar-Magnetospheric (GSM) coordinate system, which demonstrates the maxima, corresponding to the dates of the largest southward IMF component, on April 5 and October 5 (Russell and McPherron, 1973; Crooker and Siscoe, 1986). A new lack of 'Solar Illumination' mechanism (Lyatsky et al., 2001; Benkevitch et al., 2002; Newell et al., 2002) was introduced that the low ionospheric conductivity is one of the major causes in semiannual variation and predicts geomagnetic activity enhanced at equinoxes and reduced at solstices, which makes this mechanism to be similar to the equinoctial mechanism.

Studies of semiannual variation of geomagnetic activity by using long-term averages of the various geomagnetic indices give the evidence of an asymmetry between the spring and autumn equinoxes (e.g., Chapman and Bartels, 1940; Russell and McPherron, 1973; Green, 1984; Falayi and Beloff, 2009). For instance, Chapman and Bartels (1940) show that there is an asymmetry with its maximum in autumnal equinox during 1872–1930; while Green (1984) show a weak asymmetry in favor of spring equinox for the period of 1868–1979. However, the SA asymmetry cannot be well interpreted by the above mentioned semiannual variation mechanisms. Therefore, there should be some other sources for the SA asymmetry of the geomagnetic activity. Triskova (1988, 1989) analyzed the SA asymmetry in geomagnetic activity (indices aa, Ap, Dst) averaging over the roughly 10-year periods with stabilized solar polarity during 1873–1987. The results show that the SA asymmetry depends on the polarity of the main solar dipole. Mursula et al. (2011) studied the annual variation of geomagnetic activity characterized by the Ap index and the solar wind speed for the period of 1993–2008. The results show

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that the annual maxima in both the Ap index and the solar wind speed alternate between spring and autumn systematically from one solar cycle to another. They attribute the alternation to be the reversal of the Sun's polarity.

Although the alternation of the SA asymmetry during most of the intervals can be interpreted by the reversal of the main solar dipole polarity, some intervals, such as the period of 1919–1927, do not follow the alternation regulation. The change of the north-south asymmetry of the main solar dipole is thought to be a possible explanation for the break of the alternation during that period (Triskova, 1989). However, the specific reason for the influence of the north-south asymmetry of the main solar dipole on the SA asymmetry is still an open question. In addition, the SA asymmetry in recent years during which the solar wind parameters can be obtained from the spacecraft observation need to be further investigated.

In this study, based on the data from the Sun, interplanetary solar wind parameters, and geomagnetic activity, we statistically study the inherent relation of the above three regions, which could give a comprehensive interpretation of the SA asymmetry of geomagnetic activity.

2. Data and methodology

3-hourly aa index from years 1873–2010 from the National Centers for Environmental Information (NCEI) (ftp://ftp.ngdc.noaa.gov/STP/GEOMAGNETIC_DATA/AASTAR/aaindex), 3-hourly Kp index and daily Ap index from years 1940–2010 from World Data Center (WDC-C) (http://wdc.kugi.kyoto-u.ac.jp/kp/index.html), hourly averaged dawn-dusk electric field (*Ey*), southward component of the IMF(*Bs*) and solar wind bulk velocity(*V*) from years 1971–2010 come from Coordinated Data Analysis Web (CDAWeb) OMNI data (http://cdaweb.sci.gsfc.nasa.gov/index.html), are used in this study. The monthly averaged northern and southern hemisphere sunspot area data from years 1874–2010 come from Royal Observatory, Greenwich-USAF/NOAA Sunspot Data (https://solarscience.msfc.nasa.gov/greenwch.shtml).

It is no doubt that Hale's 22-year magnetic cycle is the basis for all solar activity. Turner, (1914) noted that the 11-year solar cycles are grouped in pairs, consisting of a preceding and a following cycle. Although there exists non-dipole magnetic field that contributes to the Sun's magnetic field, the dominant polarity of the interplanetary field in the northern or the southern hemisphere of interplanetary space is generally determined by the dipolar component of the Sun's field in the same hemisphere (Rosenberg and Coleman, 1969). It is indicative that solar magnetic polarity reversal takes place typically a couple of years after sunspot maxima (Wilcox and Scherrer, 1972). During some periods of the 11-years solar cycle, the solar magnetic polarity is not always stable and cannot be clearly identified, and periods with clear polarity boundary and stable solar magnetic polarity are selected as an interval. Therefore, the interval is a period where solar magnetic polarity remains the same, and it is a time span of roughly 10-years. Following the results of Makarov and Sivaraman (1986), Makarov and Makarova (1996), Dikpati et al. (2004), and Sun et al. (2015) the period of 1873–2010 was divided into 13 intervals with stabilized solar magnetic polarity. These intervals with the polarity of the northern and southern hemisphere and geomagnetic indices used are listed in Table 1.

In order to show the SA asymmetry in geomagnetic activity clearly, we have first performed a superposed epoch analysis of the corresponding monthly values of geomagnetic indices (aa, Ap and Kp) and interplanetary solar wind data (Ey, Bs and V) for the intervals in Table 1.

To characterize its SA asymmetry, the parameter Q is defined similarly as method by Triskova (1988):

$$Q = \left(\sum_{i=3}^{4} I_i - \sum_{i=9}^{10} I_i\right) \Big/ \left(\left(\sum_{i=3}^{4} I_i + \sum_{i=9}^{10} I_i\right) \Big/ 2\right)$$

Table 1
Intervals of stabilized polarity of the Sun during the period of 1873–2010.

NO	Interval	Northern hemisphere polarity	Southern hemisphere polarity	Geomagnetic indices
1	1872–1883	−	+	aa
2	1885–1894	+	−	aa
3	1895–1905	−	+	aa
4	1908–1918	+	−	aa
5	1918–1927	−	+	aa
6	1929–1939	+	−	aa
7	1940–1948	−	+	aa, Ap, Kp
8	1950–1957	+	−	aa, Ap, Kp
9	1959–1969	−	+	aa, Ap, Kp
10	1971–1980	+	−	aa, Ap, Kp
11	1982–1990	−	+	aa, Ap, Kp
12	1992–1999	+	−	aa, Ap, Kp
13	2002–2010	−	+	aa, Ap, Kp

where I is the corresponding geomagnetic indices (aa, Ap and Kp) or interplanetary solar wind data (*Ey*, *Bs* and *V*), i is the serial number of the spring or autumn months defined as the March-April (for $i = 3–4$) or September–October (for $I = 9–10$), respectively. Thus the Q-parameter represents the SA asymmetry of geomagnetic indices or interplanetary solar wind parameters, with the positive and negative sign being corresponding to the spring and autumnal maximum, respectively. We also examined the SA asymmetry calculated by using the daily averaged geomagnetic indices (not shown here) and the results appeared to be consistent with that using monthly averaged data adapted in this paper.

3. Results

Fig. 1 shows the distribution of the Q-parameters of geomagnetic indices (aa from interval 1 to 13, Ap and Kp from interval 7 to 13). Positive (negative) Q-parameters indicate the spring (autumn) maximum in the geomagnetic activity, respectively. In general, the sign of Q-parameters changes systematically from interval 1 to 13 except for the two breaks at interval 5 and 11, as indicated by two black arrows in Fig. 1. The alternation of the spring and autumn maximum in the geomagnetic activity coincide with the change of the northern and the southern hemisphere polarity of the solar magnetic field, as indicated by Table 1. However, this alternation does not appear at intervals 5 and 11, while the

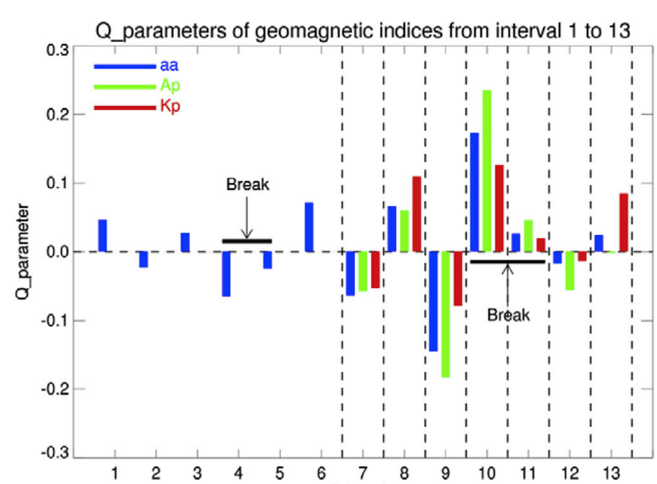

Fig. 1. The distribution of the Q-parameters of the geomagnetic indices (aa, Ap and Kp) from interval 1 to 13. The indices aa, Ap, and Kp are represented by blue histogram, green histogram and red histogram, respectively. Black arrow indicates as the breaks of the spring-autumnal alternation. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)