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SEASONAL VARIATION OF THE GEOMAGNETIC DISTURBANCE AS INFERRED FROM THE ANALYSIS OF THE AA-INDEX AND SOLAR ACTIVITY

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Abstract. The Wolf numbers (11-year cycles from 14 to 23) and global aa-index of geomagnetic activity have been used to investigate the semiannual variation of geomagnetic activity depending on the phase of the solar cycle in the even and odd cycles. Statistically meaningful maxima of geomagnetic activity recorded during the spring and autumn equinox periods urged us to search for the underlying physical mechanisms. The origin of the semiannual variation is being widely discussed by researchers. At present, there is no unambiguous explanation of this effect, but statistical reliability of the semiannual maxima near the equinoxes has aroused interest in this problem. Semiannual variations of the diurnal aa-indices have been calculated. Four phases (minimum, maximum, growth and decline) of the even and odd solar activity cycles have been analysed (see Table 1). The results have been interpreted in terms of the heliomagnetic effect on the Earth's magnetosphere and can be used in the forecast of geomagnetic disturbances.

Introduction

A semiannual variation in the geomagnetic activity (GA) was first reported in the early publications by Cortie (1912) and Bartels (1932). It appears as a growth and fall of the long-term means of various indices of geomagnetic activity. That is a typical seasonal variation with the maxima near the equinoxes and minima near the solstices. The number of the geomagnetic storms follows a similar regularity. It has been known since the XIX century (Sabine, 1856) and was widely investigated (Chapman and Bartels, 1940; Eigenson et al., 1948; Afanas'eva et al., 1960; Clua de Gonzalez et al., 2001; Svalgaard et al., 2002; Sonnemann, 2002). The semiannual variation is a global phenomenon. This follows from a similar behavior of the thermosphere dynamics (Kochansky, 1972), large-scale field-aligned currents (Ohtani et al., 2005), precipitations of high-energy electrons to the polar atmosphere (Makhmutov et al., 2003), the height of the ionospheric F2 peak (Rishbeth et al., 2000) and the peak electron density of the low-latitude F2 layer (Ma et al., 2003), and other parameters of the upper and lower Earth's atmosphere. The following mechanisms were proposed to account for the mid-latitude semiannual geomagnetic variation: the axial (Cortie, 1912; Rosenberg and Coleman, 1969), equinoctial (Bartels, 1932; McIntosh, 1959; Mayaud, 1972, 1974), and Russel-McPherron mechanisms (Russell and McPherron, 1973). In the axial hypothesis, an important role belongs to the heliographic latitude of the Earth: ~7° on the solar disk from the equatorial plane in March and September. This is when the angular distance from the solar equator is maximal and the Earth's projection is more closely aligned with both the sunspot zones and coronal holes. According to the equinoctial hypothesis, the geomagnetic disturbance enhances at the equinoxes, when the angle between the Earth's dipole axis and solar wind flow is 90°. The Russel-McPherron mechanism explains the peak in the southward component observed near the Earth in GSM coordinates in early April or October as a result of the polarity variation of the interplanetary magnetic field. This effect was regarded by many authors as the principal cause of seasonal variations of GA (Orlando et al., 1993, 1995; McPherron, 1995; Siscoe at al., 1996). Nevertheless, a series of studies have pointed out that the amplitude of the Russel-McPherron effect is too small to account for the seasonal variation in the mean indices (Mayaud, 1974; Berthelier, 1976). Following the early analysis by Roosen (1966), Lyatsky et al. (2001) and Cliver et al. (2002, 2004) have shown that the equinoctial effect is of fundamental importance. The contribution of the three modulation mechanisms (axial, equinoctial, and Russel-McPherron's) to semiannual variations depends on the particular conditions (e.g., see (Cliver et al., 2004)). We know that these conditions change over a 22-year solar cycle. The aim of this work is to study the transformations in the semiannual variation in four phases of the even and odd solar activity cycles considered separately.

Data and processing

The four phases of the even and odd Wolf number cycles are represented in Table 1. The table provides the years and the annual mean Wolf numbers W for each year. *M* and *m* are the extreme values of W in the epochs of maximum and minimum, and the month of the extreme W value is indicated in brackets after the year. The series from 1988 to 2004 contains the data for the 11-year cycles NN13-23. It is assumed that the analogous phases have similar characteristics. The daily mean aa-values for each phase of the even and odd cycles averaged over 29-day intervals are shown in Figs.1-4. Now, we can compare the graphs for the even and odd cycles in Figs.1-4.

Discussion and conclusions

The most understandable feature is the equinoctial excess of the aa-index level at the even-cycle minimum over the odd-cycle one, see Fig.4. The first explanation was proposed in (Livshits at al., 1979). It was based on anti-parallel direction of two vectors: the geomagnetic field on the magnetopause and the interplanetary magnetic field in the near-Earth space caused by the dipole magnetic field of the Sun.

Table 1

1.1. Growth phase of the odd cycle (line 3650)	**2.1. Growth phase of the even cycle** (line 3650)
10 years	10 years
Years 1915, 1916 **-15 cycle**	Years 1903, 1904 **-14 cycle**
W 47.4 57.1	W 24.4 42.0
Years 1935, 1936 **-17 cycle**	Years 1925, 1926, 1927 **-16 cycle**
W 36.0 79.7	W 44.3 63.9 69.0
Years 1955, 1956 **-19 cycle**	Years 1945, 1946 **-18 cycle**
W 38.0 141.7	W 33.1 92.5
Years 1977, 1978 **-21 cycle**	Years 1966, 1967 **-20 cycle**
W 27.5 92.5	W 47.0 93.8
Years 1998, 1999 **-23 cycle**	Years 1987 **-22cycle**
W 64.3 93.2	W 29.2
1.2. Maximum of the odd cycle (line 4015)	**2.2. Maximum of the even cycle** (line 5110)
11 years	14 years
Years 1917 (8-th month) **-15 cycle**	Years 1905 (11), 1906, 1907 **-14 cycle**
W 103.9 M	W 63.5 M 53.9 62.0
Years 1937 (6) , 1938 **-17 cycle**	Years 1928 (7) **-16 cycle**
W 114.4 M 109.5	W 77.8 M
Years 1957 (10) , 1958 **-19 cycle**	Years 1947 (5), 1948, 1949 **-18 cycle**
W 192.2 M 184.8	W 151.5M 105.5 104.5
Years 1979 (9), 1980, 1981 **-21 cycle**	Years 1968 (5), 1969, 1970 **-20 cycle**
W 155.4M 154.6 140.4	W 105.9M 105.5 104.5
Years 2000 (7), 2001, 2002 **-23 cycle**	Years 1988, 1989 (6), 1990, 1991 **-22 cycle**
W 119.6M 111.0 104.0	W 100.2 157.6M 142.6 145.7
1.3. Declining phase of the odd cycle (line 6205)	**2.3. Declining phase of the even cycle** (line 5840)
18 years	16 years
Years 1918, 1919, 1920, 192 **-15 cycle**	Years 1908, 1909, 1910 **-14 cycle**
W 80.6 63.6 37.6 26.1	W 48.5 43.9 18.6
Years 1939, 1940, 1941, 1942 **-17 cycle**	Years 1929, 1930, 1931 **-16 cycle**
W 88.8 67.8 47.5 30.6	W 64.9 35.7 21.2
Years 1959, 1960, 1961 ,1962,1963 **-19 cycle**	Years 1950, 1951, 1952 **-18 cycle**
W 159.0 122.3 53.9 37.6 27.9	W 83.9 69.4 31.4
Years 1982, 1983, 1984 **-21 cycle**	Years 1971, 1972, 1973, 1974 **-20 cycle**
W 115.9 66.6 45.9	W 66.6 68.9 38.0 34.5
Years 2003, 2004 **-23 cycle**	Years 1992, 1993, 1994 **-22 cycle**
W 63.6 40.4	W 94.3 54.6 29.9
1.4. Minimum of the odd cycle (line 4745)	**2.4. Minimum of the even cycle** (line 5110)
13 years	14 years
Years 1899, 1900, 1901, 1902 **-13 cycle**	Years 1911, 1912, 1913, 1914 **-14 cycle**
W 12.1 9.5 2.7 m 5.0	W 5.7 3.6 1.4 m 9.6
Years 1922, 1923, 1924 **-15 cycle**	Years 1932, 1933 , 1934 **-16 cycle**
W 14.2 5.8 m 16.7	W 11.1 5.7m 8.7
Years 1943, 1944 **-17 cycle**	Years 1953, 1954 **-18 cycle**
W 16.3 9.6 m	W 13.9 4.4 m
Years 1964, 1965 **-19 cycle**	Years 1975, 1976 **-20 cycle**
W 10.2m 15.1	W 15.5 12.6m
Years 1985, 1986 **-21 cycle**	Years 1995, 1996, 1997 **-22 cycle**
W 17.9 13.4m	W 17.5 8.6m 21.5

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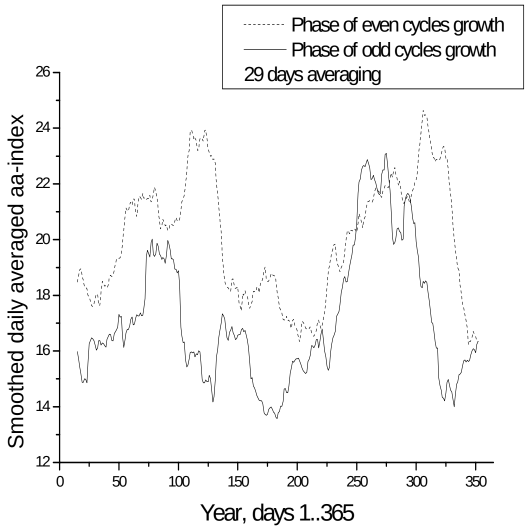

Fig. 1

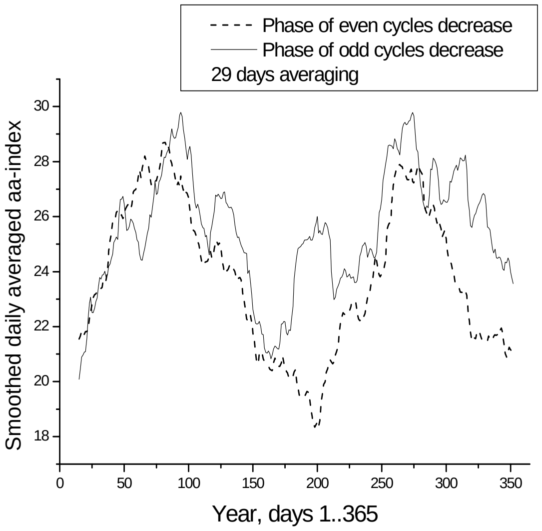

Fig. 3

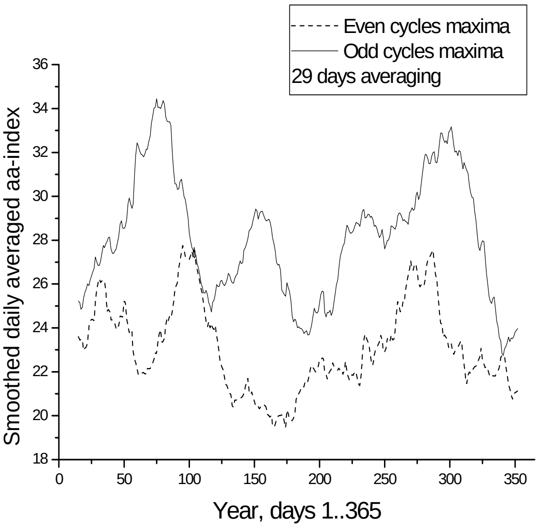

Fig. 2

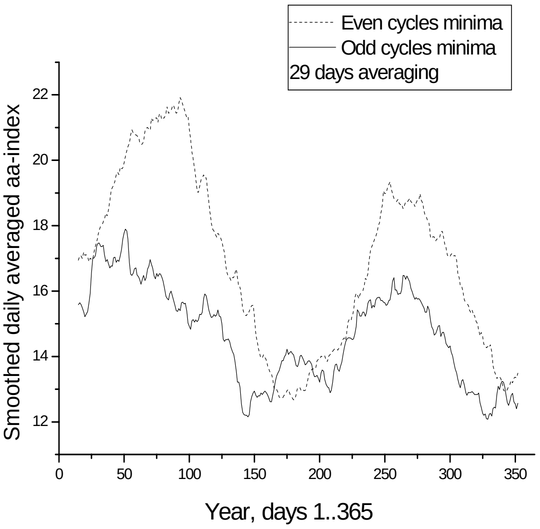

Fig. 4

The same features are clearly revealed in the semiannual variation. We see that the even-cycle aa values dominate (Fig.1, growth phase of the solar cycle) like at the solar minimum. Probably, in the growth phase, the active regions of "old" polarity still exist at low heliographic latitudes (while the new ones are generated at higher latitudes), and their effect is similar to that of the minimum-phase features but has a more stochastic form. The maximum phase (Fig.2) is characterized by the largest modulation of the aa-values. The smoothed daily mean aa-indices are higher in the odd than in the even cycle. The picture is most stochastic. It can be suggested that the even-cycle W maxima have greater effect on the GA seasonal variation than the odd-cycle ones. Fig.3 represents a long declining branch of the solar cycle. Here, the picture is rather regular, and the even and odd cycles are similar. The solstice points have the characteristic features illustrated in Figs.1-4.

The conclusions drawn from the analysis can be summarized as follows.

The amplitude modulation of the semiannual variation differs in different phases of the even and odd solar cycles (Figs.1-4). At the equinoxes, the smoothed aa-indices (Fig.3) are most similar in the declining phase of solar activity and differ in the phases of maximum (Fig.2) and minimum (Fig.4). At the maximum, the smoothed aa-values in the odd cycles are greater than in the even ones. At the minimum, on the contrary, the even-cycle aa-values exceed the odd-cycle ones significantly. The behaviour of the aa-index in the growth phase of the even and odd cycles is less regular (Fig.1). During the summer solstices, the smoothed aa-values are greater in the odd than in the even cycle, except for Fig.1 where the aa-indices in the growth phase of the even cycle exceed the values observed in the growth phase of the odd cycle.

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