GEOPHYSICAL RESEARCH LETTERS, VOL. 22, NO. 23, PAGES 3287-3288, DECEMBER 1, 1995

The 22-year variation of geomagnetic activity: Implications for the polar magnetic field of the Sun

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Abstract

We examine the average behavior of the aa index and its recent extension using proxy data over the period 1844 to the present. Over this period the daily average aa index fell from an average of about 18 in 1850 to a low of about 14.4 in 1900 to a high of 23 over the most recent solar cycles. Independently the amplitude of the 22-year variation of geomagnetic activity has also changed. It was its largest in the years 1862 to 1908 when it reached 30% of the mean activity but has been close to 0 in other years except from 1949 to 1970 when it was about 15% of the mean level of activity. Because the 22-year variation of geomagnetic activity is thought to be associated with the reversals of the polar magnetic field of the sun, these latter variations suggest that the strength of the polar magnetic field of the sun varies considerably over the long term.

The 22-year cycle of geomagnetic activity is characterized by an 11-year period in which geomagnetic activity is greater than average followed by an 11-year period when the activity is less [Chernosky, 1966]. The phase of this cycle is offset with respect to the usual 22-year sunspot magnetic cycle. It begins about 2 years after solar maximum when the polar magnetic field reverses. Russell [1974] attributed this effect to control by the solar polar magnetic field of the heliographic latitude dependence of the dominant polarity of the interplanetary magnetic field (IMF) and its subsequent effect on the semi-annual variation of geomagnetic activity [Russell and McPherron, 1973]. These authors had shown that the heliolatitude dependence of the dominant polarity of the IMF could lead to either enhanced or diminished geomagnetic activity depending on its phase. This 22-year variation was first studied by Russell [1974] in the Ci index to determine if the presence of heliographic latitude variation of the solar wind could be inferred over long periods. This study was then repeated by Russell [1975] when the more objective aa index became available [Mayaud 1973]. The period covered by that study included 9 "11-year" cycles from 1892 to 1971. The study showed that the 22-year average geomagnetic activity remained fairly constant from 1872 to around 1908 and then climbed to a peak about 1949 to 1960, increasing by about 60% to a maximum at which it stayed at least through 1971.

Paper number 95GL03086
0094-8534/95/95GL-03086$03.00

Almost 20 years have passed since that study and we can now add two 11-year solar cycles to the aa record. We can also add three 11-year solar cycles to the beginning of the aa time series due to the efforts of Nevanlinna and Kataja [1993] who have calculated a pseudo aa index to the year 1844 using Helsinki D values as a proxy measure for the English and Australian K values scaled by Mayaud [1973] from which the aa index had been created. (See also Nevalinna [1995]). It is the purpose of this paper to use these five additional 11-year cycles to extend our earlier analysis both forward and backward in time to infer the long term behavior of the heliographic dependence of the IMF and its possible source in the polar magnetic field of the sun.

Figure 1 shows in the lower panel the "11-year" solar cycle average of the aa index beginning two years after solar maximum (heavy line), together with the double solar cycle average which removes the "22-year" periodicity. The double sunspot average is centered on and calculated for each solar cycle. The error bars are the probable errors in the mean derived from the standard deviation of the annual average aa indices from the "11-year" average aa index. The top panel of Figure 1 shows the amplitude of the "22-year" variation, that is, the ratio between the 11-year average and half the sum of the neighboring cycles, inverting every second ratio. The amplitude is significantly different from zero from 1862 to 1908 and 1949 to 1970 but not significantly different at other times. The average geomagnetic field has also varied. The average aa value was about 18 in 1850. It fell to a minimum of 14.4 in about 1900 and then rose to a high of about 23 over the last five solar cycles.

In conclusion it is clear that there have been long term changes in geomagnetic activity both in the average activity and in the amplitude of the 22-year cycle. These variations in turn imply that there are very long term variations in the sun. The long term variation of the aa index may be caused by a long term variation in the solar wind velocity, the solar wind density or the IMF. Since the 22-year cycle has been linked to the polar field of the sun, we infer that variations of its amplitude are due to variations in the magnitude of the polar magnetic field of the sun. An alternative way of visualizing this is to consider the control of the heliospheric current sheet by a tilted dipole in the sun. When the dipole axis is in the ecliptic plane, the amount of inward and outward IMF is equal at all latitudes and there is no heliographic latitude effect in the semi-annual variation of geomagnetic activity. When the dipole is aligned with the sun's rotaion axis, and in the absence of ripples in the

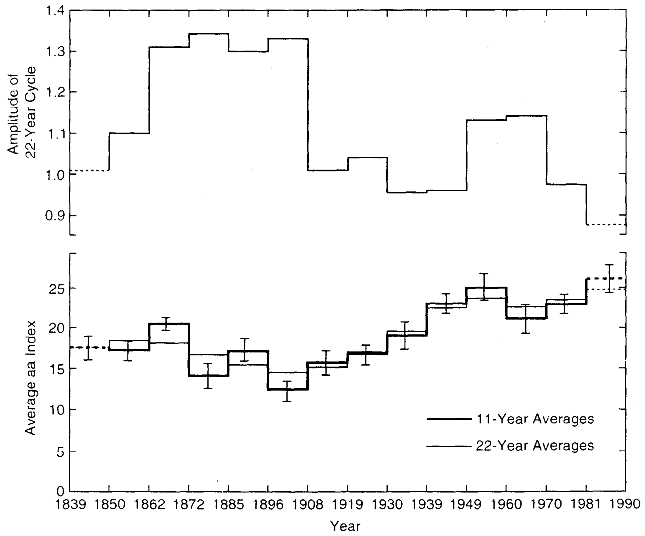

Figure 1. Long term variation of geomagnetic activity as deduced from the aa index. (Lower panel) Heavy line shows the 11-year solar cycle average aa index beginning two years after solar maximum. Fine line in 22-year average centered on the 11-year averages. Error bars are probable errors in the mean. (Upper panel). The amplitude of the double solar cycle.

current sheet, the Earth will be in the northern field of the sun for 6 months and then the southern for 6 months, giving the maximum heliographic latitude effect. Interpreted either way our study suggests that the field in the polar regions of the sun varies on time scales longer than the 11- or 22-year sunspot cycle.

Acknowledgments. The authors wish to thank S. K. Runcorn for repeated requests to extend this study over a longer baseline. This work was supported by the National Aeronautics and Space Administration under research grant NAGW-3948.

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(Received October 31, 1994; revised March 7, 1995; accepted June 15, 1995.)