# On the long-term variability and predictability of the geomagnetic activity

Pavel Hejda, Ivanka Charvátová, Jaroslav Střeštík, *Institute of Geophysics of the ASCR, Prague, Czech Republic*

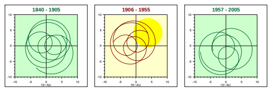
**Abstract** Geomagnetic activity is a result of processes on the Sun, in the interplanetary space and in the Earth magnetosphere. Although these processes are nowadays quite good understood and described by physical equations, an exact modeling of the time behavior of geomagnetic activity is still not possible and most of recent studies are based on different approaches in time series analysis. The long-term behavior of geomagnetic activity can be best described by the series of aa-indices. This longest series of geomagnetic indices dates back to 1868. In the present contribution, extension made by Nevanlinna and Kataja (1993) back to 1844 from measurements taken in Helsinki are used.

**Our approach is based on the relation of geomagnetic activity to the solar inertial motion (SIM).** The SIM is motion of the Sun around the barycenter of the solar system due to variable positions of the giant planets (Jupiter, Saturn, Uranus and Neptune). The SIM is composed of two types, the ordered in trefoils and the disordered. The SIMs in the years 1840-1905 and 1980-2045 are of disordered type and are nearly identical. A similarity between the variabilities of geomagnetic *aa*-index in the intervals 1844-1867 and 1984-2007 was found. Moreover, the *aa*-index in these intervals have the same best fit lines (the polynomials of the fourth order) with close positions of the extrema. The correlation coefficient between the *aa*-indices in the interval 1844-1867 and in the interval 1984-2007 is 0.61. Close similarity between the above mentioned sequences of the SIM and a similarity of the *aa*-indices in the intervals 1844-1867 and 1984-2007 were used for establishing of a cautious predictive assessment of a course of the geomagnetic *aa*-index up to 2045: After 2007, the *aa*-index could copy its values from the interval 1868-1905.

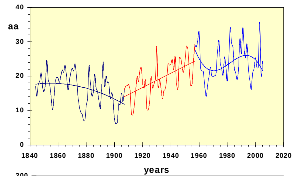
The above facts on relation between *aa*-index and the SIM can be supported by similar results obtained former for (much longer) series of sunspot numbers. **The results indicate that geomagnetic (solar) activities are non random processes.**

## The *aa*-index and geomagnetic variability since 1844

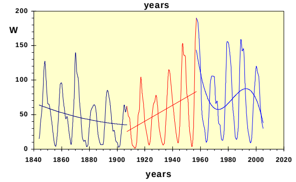
The *aa* index is a simple global geomagnetic activity index, with units of 1 nT, which is produced from the K indices from two approximately antipodal observatories (Mayaud, 1973). At the beginning there were Greenwich observatory in England and Melbourne observatory in Australia. The *aa*-index is available since 1868. Nevanlinna and Kataja (1993) extended the *aa*-index series back to 1844 from measurements taken in Finland (Helsinki). Even if there is a good conformity (for the time period 1868-1880 the linear correlation coefficient between the two indices was 0.96 on the monthly basis), one must be aware of lower reliability of the data.



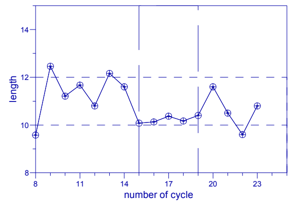

**a)** The solar orbit between 1840 and 2005 plotted in the three partial intervals:
1840-1905 (the SIM of disordered type)
1906-1956 (the trefoil, stable type)
1957-2005 (the SIM of a slightly disordered type which differs from that of the first interval).




**b)** The *aa*-index of geomagnetic activity 1844-2005 divided into three intervals according to different types of the SIM. The best fit line for the first interval is the polynomial of the second order, it is the straight line for the second (trefoil) interval and it is the polynomial of the third order for the third interval.

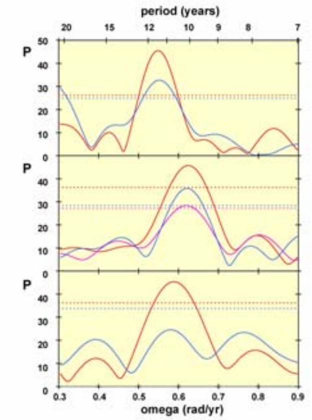



**c)** The record of Wolf sunspot numbers 1844-2005 divided into three intervals according to different types of the SIM. The best fit line for the first interval is the polynomial of the second order, it is the straight line for the second interval and it is the polynomial of the third order for the third interval.




**d)** The lengths of the sunspot cycles No 8-23. Notice that during the trefoil interval of the SIM (denoted by the vertical lines) the lengths of the solar cycles No 15-19 are nearly constant (10.1 years, on the average), while the lengths before and onward are variable. The motion of the Sun along one motion loop lasts 10 years (JS/2) during the trefoil motion.

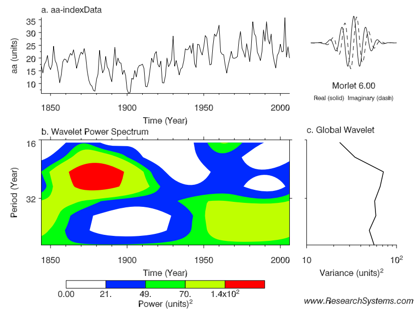
Charvátová and Střeštík (2007) showed that the basic properties of the *aa*-index correspond to those of the SIM, exhibiting a 10 year periodicity and a stationary behaviour during the ordered trefoil interval, etc. The behaviour of *aa*-index resembles that of sunspots numbers W.




Top: the spectrum for the first interval has dominant period of 11.3 years for the sunspot numbers (red line) and it has dominant period of 11.4 years for the index *aa* (blue line). Confidence levels (99%) are presented by lines of the same colours as the respective spectra.

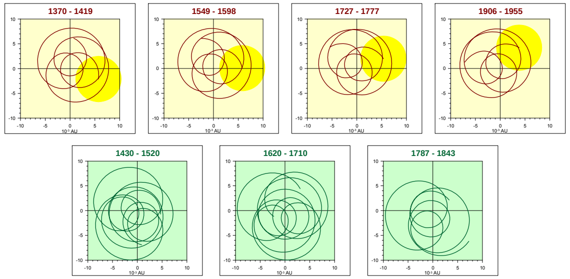
Middle: the dominant period in the second (trefoil) interval 1906 – 1956 for the *aa*-index is 10.1 years (blue line). This corresponds to the duration of SIM along one motion loop (JS/2). The spectrum for the sunspot numbers in this interval also shows dominant period of 10.1 years (red line). The spectrum for the sunspot numbers from the previous trefoil interval 1727-1777 is added (purple line). Note that all the three spectra have very similar pattern including the lover side periods.

Bottom: the spectrum for the third interval differs from that for the first interval. It has dominant period of 10.8 years for the sunspot numbers (red line) and of 10.7 years for the index *aa* (blue line).




Wavelet power spectrum for the periods higher than 16 years (Torrence and Pompo, 1998) computed for the interval 1844-2006, yearly data was taken. These longer periods occur before and after the trefoil interval of the SIM

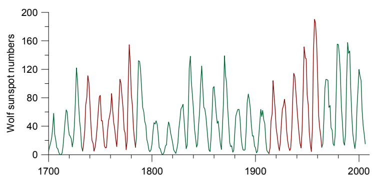
## Solar inertial motion and solar variability




The Solar Inertial motion (SIM) is the motion of the Sun around the centre of mass of the Solar System due to variable positions of the giant planets (J-Jupiter, S-Saturn, U-Uranus, N-Neptune). The area in which the Sun moves has the diameter of 0.02 AU or 4.3 $r_s$, this being solar radius, or $3.10^6$ km.

Charvátová (1988, 1990a,b, 1997) divided the SIM into two basic types: the ordered ones in a trefoil according to the JS motion order and the other disordered (chaotic).

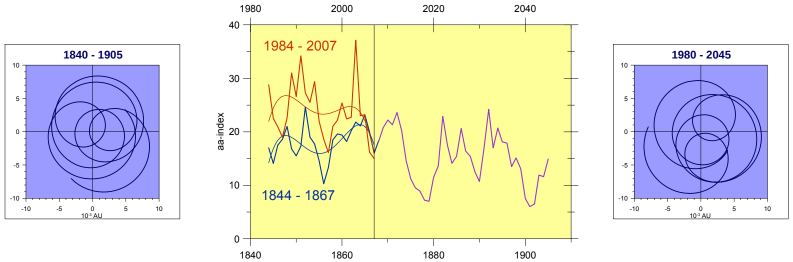
The upper part of the figure shows four trefoils periods. The most disordered sections of the intervals lying between the trefoils are plotted in the bottom part. They coincide with the prolonged (Grand) minima of solar activity, such as, here, the Spörer (cca 1430 – 1510), the Maunder (cca 1620 – 1710) and the Dalton (cca 1790 – 1840) minima. The Sun enters into the trefoils in steps of 178.7 years, on the average. The Sun moves along a trefoil (along one of the loops), over 50 (10) years, respectively. The yellow circle shows the solar disk in the beginning of the trefoil part of the SIM.




If the solar variability is really modulated by the SIM, the motion of the Sun along the same orbits (with the same motion characteristics such as the velocity, the acceleration, the radii of curvature, etc.) should create the same series of solar cycles. Charvátová (1990b, 1995a,b,c, 1997a, 2000) showed that the Sun moving along the same trefoil orbits (i.e. in the years 1727-1777 and 1906-1956) created nearly the same series of sunspot cycles (-1 to 3 and 15 to 19). The only significant correlation coefficient (0.81) is between these series of five sunspot cycles

## Orbital similarity in the intervals 1840-1905 and 1980-2045

On the basis of orbital similarity in the intervals 1840-1905 and 1980-2045, investigations were carried out to see whether the variations in geomagnetic activity were similar in these two time intervals. Unfortunately, this limits the period of overlap to 24 years for the *aa*-index (1844-1867 and 1984-2007).




The best fit lines (polynomials of the fourth order) were computed and plotted both for the *aa*-index in the interval 1844-1867 and in the interval 1984-2007. They show similar variations with their extrema nearly coinciding. The correlation coefficient between these two data series is 0.61. The curves support the opinion that these two series (1844-1867 and 1984-2007) would have been more similar had the *aa*-data in the first interval been more reliable (i.e. been measured at two basic stations rather than from one station in Helsinki). Hence, a proper prediction of the future variation of the *aa*-index is not being made at this stage. **The purple line is plotted up to 1905 to indicate an assessment of future development of the *aa*-index up to 2045**.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## Concluding remarks and tentative predictive assessments on the basis of the orbital similarity between the sequences of the SIMs (1840-1905 and 1980-2045)

Since there is a similarity in the *aa*-indices between the above mentioned time intervals 1844-1867 and 1984-2007, predictive assessments for the next sequence of geomagnetic activity could be made up to 2045. Due to the lower data quality in the beginning of the data series studied, this study can only give a rough indication of future changes. If the future values are in accord with the more precise data from the 19th century (after 1868), the predictions would be significantly improved, since they should be identical with the previous SIM sequence.

The results indicate that the **variability of the geomagnetic activity is non random process**.

It is possible to see here that it could behave under the „baton“ of the SIM, that the SIM could be the solid physical underpinning (underlying physics) for it. If this is the case, it is reasonable to expect that the coincidence between the next geomagnetic variations and those from the interval 1868-1905 should get better and better as more precise data from the 19th century is taken into account, allowing the comparative series to become longer and longer.

From the year 2008 onwards, we can start to observe whether the *aa*-index really varies in the same manner as it did after 1868 when more reliable data was available. If the coincidences between the respective series gradually increase over the next few years, the predictions that could be made would become more and more reliable. In an opposite sense, the coincidences between the series could be used as further evidence **supporting the idea that the SIM modulates and governs the geomagnetic activity (the *aa*-index).**

The geomagnetic activity (the indices *aa*, Ap) is sometimes employed for predictions of solar activity. A long-term course of the geomagnetic activity itself has not been so far predicted.


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