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Long-term predictive assessments of solar and geomagnetic activities made on the basis of the close similarity between the solar inertial motions in the intervals 1840–1905 and 1980–2045

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ABSTRACT

The solar inertial motions (orbits) (SIMs) in the years 1840–1905 and 1980–2045 are of a disordered type and they are nearly identical. This fact was used for assessing predictive capabilities for the sizes of three future sunspot cycles and for the time variation of the geomagnetic *aa*-index up to 2045. The author found that the variations in sunspot numbers in the interval 1840–1867 and in the interval 1980–2007 are similar, especially after 1850 (1990). The differences may be ascribed to the lower quality of the sunspot data before 1850. A similarity between the variations in geomagnetic *aa*-index in the intervals 1844–1867 and 1984–2007 is also 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 extrema of the best fit line for the *aa*-index in the interval 1906–1928 which corresponds to the first half of the ordered, trefoil interval of the SIM have the opposite positions to them. The correlation coefficient between the *aa*-indices in the interval 1844–1866 and in the interval 1984–2006 is 0.61. In contrast, the correlation coefficient between the *aa*-indices in the interval 1844–1866 and in the interval 1906–1928 is −0.43. Cautious predictions have been made: the author believes that the cycles 24–26 will be a repeat of cycles 11–13, i.e. they could have heights around 140 (100), 65 and 85, they will have lengths of 11.7, 10.7 and 12.1 years. The maxima of the cycles should occur in 2010, 2023 and 2033, the minima in 2007, 2018, 2029 and 2041. Up to 2045, the *aa*-index could repeat its values for the interval 1868–1905. The results indicate that solar and geomagnetic activities are non random processes. If these predictions may come true, then further evidence of the primary role of the SIM in solar variability is established.

1. Introduction

Prediction of future solar activity is one of the basic goals of solar physics. Since the prediction of solar activity by physical methods (i.e. by a proper mechanism that is continuously valid) is still not possible, forecasting of future solar activity have been made by many different indirect proxy methods (skills, techniques, models or tools). The NOAA, NASA and ISES panel for the prediction for solar cycle 24 (Zielinski, 2007) evaluated more than 40 predictions for the peak sunspot count for this cycle that range from 42 to 185. The consensus prediction was based on six techniques, three based on statistics and three based on the theory of the Sun‘s dynamo conveyor belt. (It was noted in that Panel that if a method does not accurately predict the solar cycle 23 minimum, it will also likely fail to predict the timing, duration and intensity of the next peak.)

All the methods (skills, tools or models) used for the size (height, length and timing) of cycle 24 prediction were very different, and the differences among the predicted values indeed cover a very wide range. Despite the large number of methods used and inspite of the best modern observational techniques, the forecasts for cycle 24 are still widely scatterred, from 42 to 200 W.

Badalyan et al. (2001) predicted the behavior of W (Wolf sunspot numbers) in the next cycle on the basis of intensities of the coronal green line in the preceding cycle: 50 W in 2010–2011. Sun et al. (2002) made a preliminary prediction 101.3 ± 18 W on the basis of the two groups of cycles: those of high rising velocity cycles and low rising velocity cycles. Duhau (2003) employed a wavelet analysis of the geomagnetic *aa*-index and the sunspot numbers and found that solar activity is in a declining episode and predicted 87.5 ± 23.5 W. Hathaway and Wilson (2004) published a prediction of 145 ± 30 W based on the equatorial drift rate of active latitudes during cycle 22. Svalgaard et al. (2005) predicted a low activity peak of (75 ± 8 W) based on the weak polar fields observed on the Sun during the decline of the sunspot cycle 23.

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A similar result (74 ± 10 W) was obtained by Javaraiah (2007) for the upcoming solar cycle 24 using Greenwich and Solar Optical Observing Network sunspot group data obtained during the period 1874–2005 in the vicinity of sunspot cycles extrema. Schatten (2005) used the polar field precursor method and estimated 80 ± 30 W in terms of smoothed Rz (Rz are the Zurich sunspot numbers, see e.g. in the database http://ngdc.noaa.gov/stp/stp . . .) Dikpati et al. (2006) employed historical records over the last 130 years as an input for the source of the surface magnetic fields that seed the solar dynamo and they predicted an amplitude 165 ± 15 W. Du (2006) used the max–max cycle length and obtained 150.3 ± 22.4 for cycle 24 and 102.6 ± 22.4 for cycle 25. Li et al. (2005) predicted a peak amplitude of 189.9 ± 15.5 W if the cycle's activity is rising fast or 136 W if the cycle is rising slowly. Hathaway and Wilson (2006) employed the geomagnetic *aa*-index and predicted 160 ± 25 W. Kane (2007) used Ohl's precursor method and predicted a maximum height of 142 ± 24 W which is expected to occur in 2011–2012. Hiremath (2007) attempted to predict future fifteen solar cycles using solar cycles modelled as a forced and damped harmonic oscillator in the interval 1755–1996. Acording to Hiremath (2007), the height of cycle 24 should be 110 W and the length 9.34 years, cycle 25 should have the same height, 110 W, while the heights of cycles 26 and 27 could be much higher.

Tobias et al. (2006) even casts doubt about the predictive possibilities for the solar activity (unpredictable magnetism of the Sun). Similarly, Busby and Tobias (2007) arrived at a conclusion that it is impossible to predict the height of sunspot cycles if one uses the outputs from models based on stochastic or deterministic processes. Choudhuri et al. (2007) predict that cycle 24 will be about 35% weaker than cycle 23 (about 80 W).

All the predictions for the cycle 23 height were always high or very high (140–225 W), see e.g. Kane (1997), Shatten et al. (1996) or Obridko (1995).

The only successful prediction of the peak sunspot number for cycle 23 (i.e. 65–140 W) was that made earlier by Charvátová (1995a, 1997a) based on the similarity between the SIM in the years 1840–1905 and 1980–2045 (using the mean value for heights of cycles 9–13). The actual peak sunspot number reached by cycle 23 was 121 W, significantly below the lowest prediction proposed by others of 140 W.

Moreover, there are not only a large dispersion or uncertainty in the forecasts of cycle heights but also in the forecasts of the timing of extrema. For instance, the predicted timings for the maximum of cycle 24 range from 2010–2011 (e.g. Badalyan at al., (2001) to 2014 (e.g. Tsirulnik et al., 1997)).

It is evident that predictive methods not based on the knowledge of a proper physical mechanism of solar variability have been unsuccessful.

Relations between the solar inertial motion (SIM) and solar variability have been studied for more than 40 years. The SIM is the motion of the Sun around the centre of mass of the Solar System

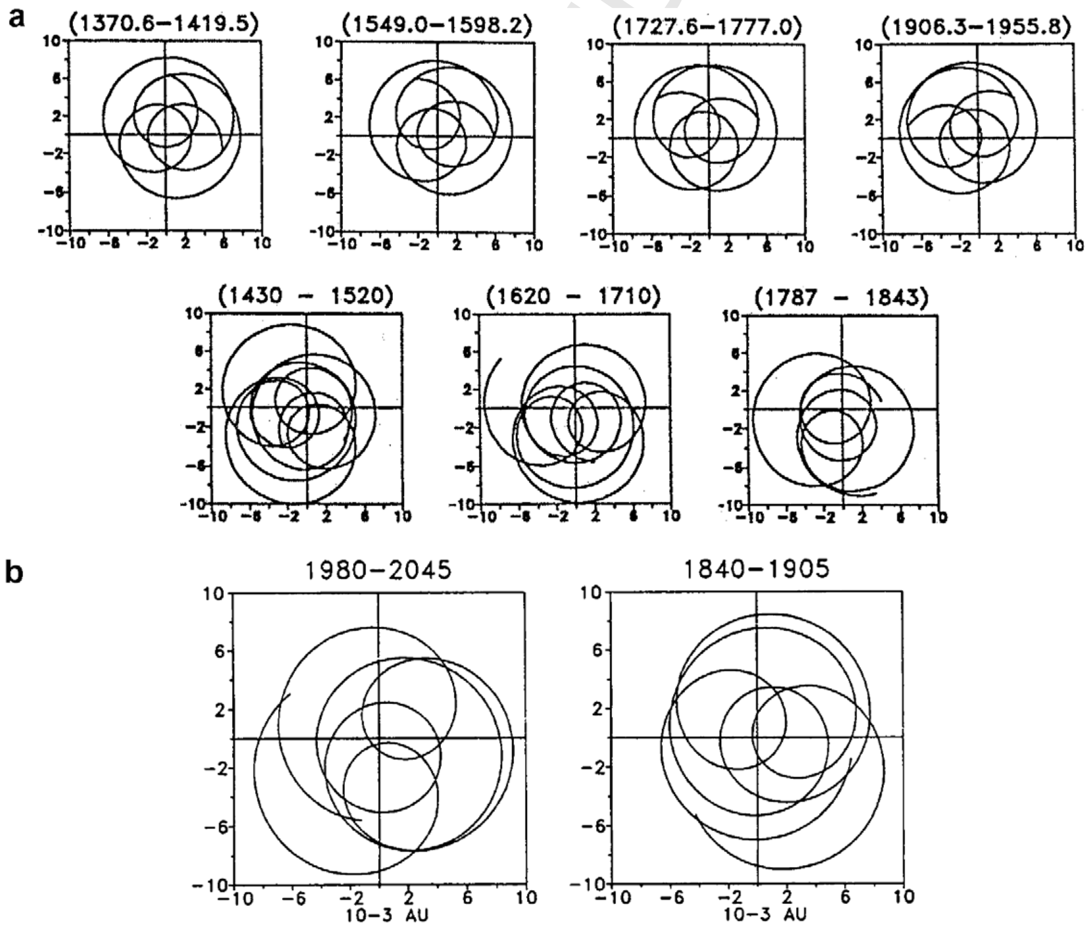

Fig. 1. (a) The solar orbit of the center of the Sun around the center of mass of the solar system (in units of 10^{-3} AU) separated into two basic types, the ordered (in a JS-trefoils) (top) and the disordered (bottom). The area in which the Sun moves has the diameter of 0.02 AU or $4.3r_s$, this being solar radius, or 3×10^6 km. The most disordered sections of the intervals lying between the trefoils are plotted. They coincide with the prolonged (Grand) minima of solar activity, such as, here, the Spörer, the Maunder and the Dalton 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. (b) The solar orbits in the intervals 1980–2045 and 1840–1905. Notice that they are, after a rotation of the whole orbit configurations (by about 90°), nearly identical.

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due to variable positions of the giant planets (J – Jupiter, S – Saturn, U – Uranus, N – Neptune). The first study was published by Jose (1965). He noticed this sentence in Newton‘s Principia (see Cajori, 1934):“. . . since that centre of gravity (center of mass of the solar system) is continually at rest, the Sun, according to the various positions of the planets, must continually move every way, but will never recede far from that centre.” The SIM studies have been made by means of statistics, by means of spectral analyses, by means of studying a behavior in the basic exceptional formations (e.g. during the trefoil intervals Charvátová, 1990b), etc.

Further investigations of the relations between the SIM and solar (also solar-terrestrial) variability were published, e.g. in Fairbridge and Hameed (1983), Bucha et al. (1985), Jakubcová and Pick (1987), Fairbridge and Shirley (1987), Charvátová-Jakubcová et al. (1988), Charvátová (1988, 1990a,b, 1995a,b,c, 1997a,b, 2000, 2006, 2007), Charvátová and Střeštík (1991, 2007), Landscheidt (1999), Shirley et al. (1990), Shirley (2006), Zaquarashvili, 1997, Juckett (2000, 2003), Paluš et al. (2000, 2007) and Wilson et al. (2007).

Charvátová (1988, 1990a,b, 1997a) divided the SIM into two basic types (Fig. 1a), the ordered ones in a trefoil according to the JS motion order and the other disordered (chaotic). (Note: the conjunctions of the planets J and S occur once every 19.86 years, with each successive conjunction advancing by 117.3° in a prograde direction.) In case of the ordered trefoil motion, the Sun orbits the centre of mass of the solar system along a loop (arc) about once every 10 years (JS/2). The Sun always returns to the ordered trefoil SIM after 178.7 years and this type of motion lasts about 50 years. The most disordered parts of the SIM correspond with the prolonged (Grand) decreases of solar activity, over the last millennium known as the Spörer, Maunder and Dalton minima.

If solar variability is really caused 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 induce the similar 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 similar series of sunspot cycles (-1 to 3 and 15 to 19). Only the correlation coefficient between these series of five sunspot cycles is significant (0.81). The differences may be ascribed to substantially lower quality of sunspot data in the 18th century, especially before 1750 where only annual values are available. The number of daily observations is low, particularly in the years when there is little similarity between the two sunspot number series (Charvátová, 1990b). The lengths of solar cycles are nearly constant in both the cases (it is seen especially in the series of the cycles 15–19, where precise values are available) and equal, on average, to 10.1 years. This value corresponds to the duration of the motion of the Sun along one motion loop (arc) (JS/2). The spectra of periods of the sunspot numbers from these two intervals are nearly the same with the dominant periods of 10.1 years (Charvátová (1990b), Charvátová and Střeštík (2007)). Benestad (2005) used several methods to estimate the lengths of the sunspot cycles since 1700. He found the same exceptional intervals where sunspot cycles have nearly stable lengths of 10 years. Similarly, Li et al. (2005) (Fig. 2) highlighted the cluster of cycles 15–19 by noting that these cycles have stationary lengths near 123 months (10.1 years).

Paluš et al. (2000, 2007) found phase synchronization between the sunspot cycles and the SIM. This was statistically confirmed for three epochs: 1734–1790, 1855–1875 and 1907–1960, matching the two intervals over which the Sun moved along similar trefoil orbits i.e. 1727–1777 and 1906–1956. (In the years 1855–1875 one half of the trefoil occurs.) Palus‘ study covered the period 1700–2000 and the results give the first quantitative support to the hypothesis that there is an interaction between the SIM and solar variability.

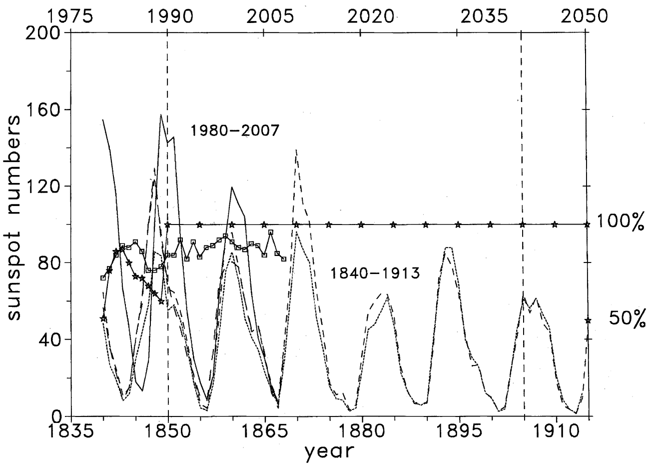

Fig. 2. The sunspot numbers in the years 1840–1905 (dashed line) and in the years 1980–2007 (solid line). The dotted line represents the Group sunspot numbers (Hoyt and Schatten, 1998). The data were taken from the database: http://ftp.ngdc.noaa.gov/stp/stp . . . The numbers of daily observations (in percents) are plotted by solid line with asterisks. The long dashed line represents Schwabe's "Clusters of spots (Cs)" expressed as Wolf numbers W (Wilson, 1998). In this case, the numbers of daily observations (in percents) are plotted by solid line with squares. One can see lower coincidence before 1850 when the number of daily observations is low, incomplete, only between 53% and 85% and when sunspot numbers were not measured by any uniform method. Further, one can see that the numbers of daily observations of Cs in the interval 1840–1850 is higher (72–91%) than those of Wolf numbers. A better coincidence between cycles 9 and 22 occurrs between W and Cs. The yearly sunspot number for 2007 was taken from the database: http://sidc.oma.be. The sunspot cycles in the interval 1868–1905 (dashed line) represent a possible development of future cycles 24–26 (2008–2042).

It is not only the ordered trefoil types that repeat themselves every 179 years. Identical sequences of more or less chaotic type are repeated in the SIM as well (e.g. the SIM sequence in the years 244–300 AD is repeated in the years 1787–1843, with a prolonged minima of Dalton type occurring in both cases.)

Further long-term evidence of relations between the SIM and solar variability was given by Charvátová (2000). She showed that for 8000 years long series, there were exceptional intervals in the long-term trefoil SIM with 370-years long durations which repeated themselves in steps of 2402 years (i.e. 158 BC to 209 AD, 2560 BC to 2193 BC, 4962 BC to 4595 BC). Charvátová (2000) found that these unusual trefoil patterns were imprinted into the ^{14}C records as exceptional stationary intervals of the same length.

All these investigations revealed that solar variability may be linked to the SIM, and that the SIM could be the key factor affecting solar variability. The layered Sun is forced to move along deterministically given orbit. The greatest jump in the physical properties is at the boundary between the convective and radiative zones. The thin layer called the tachocline where a shear flow was recorded by SOHO-MDI "is likely to be the place where the solar dynamo operates" (Kosowichev et al., 1997).

The SIM can be computed in advance. Although a physically valid mechanism linking the SIM to the level of solar activity has not been found as yet, all the results assembled up to now about the mutual relations between solar variability and the SIM can be used to further test the SIM-solar variability relation theory.

Predictive assessments can be so far made on the basis of similarity between the SIM sequences in the years 1840–1905 and 1980–2045 (Fig. 1b) where the good quality data can at least be partially employed. In Fig. 1b, one can see the similarity between these two orbital configurations after the second one was rotated by about 90°.

This similarity was found by Charvátová (1995a, 1997a). At that time (1995–1997), the overlap period that allowed comparative

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studies to be made between the two series was only 10–12 years long. Only a general prediction for sunspot numbers was made at that time: the height of the sunspot cycle 23 can be within 65–140 W, which is the range of heights of the sunspot cycles during the interval 1840–1905. This general prediction was successful, as the maximum height of cycle 23 turned out to be 121 W. (As noted before, those predictions by other methods gave much higher values, ranging from 140 to 240 W).

The author made predictive assessments for both the solar and geomagnetic activities (i.e. the sunspot number and the *aa*-index) for three solar cycles up to about 2045. Geomagnetic activity is of course closely connected with solar activity but it has its proper own intrinsic variability. The *aa*-index is sometimes employed to make predictions of solar cycle height (e.g. Duhau (2003), Hathaway and Wilson (2006)). Charvátová and Střeštík (2007) show that the basic properties of the *aa*-index correspond to those of the SIM, exhibiting a 10 year periodicity and a stationary behavior during the ordered trefoil interval, etc. However, the long-term variations of the *aa*-index itself has not yet been predicted.

On the basis of orbital similarity in the intervals 1840–1905 and 1980–2045, investigations were carried out to see if the variations in solar and geomagnetic activities were similar in these two time intervals. Unfortunately, this limits the period of overlap to 28 years for the sunspot numbers (1840–1867 and 1980–2007) and 23 years for the *aa*-index (1844–1866 and 1984–2006).

Moreover, the sunspot numbers before 1850 are of significantly lower quality. The numbers of daily observations were between 53% and 85% only (Fig. 2, solid line with the asterisks) and sunspot numbers were not measured by a uniform method. The uniform method was described by Wolf (1848). The Group sunspot numbers (Hoyt and Schatten, 1998) are shown by the dotted line in Fig. 2. They are nearly identical with $R_z(W)$ (including the heights) since cycle 10. The monthly values of sunspot numbers for October, November and December 2007 are very close to zero. These values of the first months 2008 are higher. So, end of 2007 may be the minimum of cycle 23.

The lack of good quality sunspot data prior to 1850 is probably the reason why the amplitudes of cycles 9–10 are lower than those of the cycles 22–23 which are measured more precisely.

The sunspot cycle minimum in 1867 is repeated after 140 years in 2007. Wilson (1998) compared the Wolf sunspot numbers with Schwabe‘s record of ‘‘Clusters of spots (Cs)” for the interval 1826–1868. Schwabe, 1868 values (expressed in sunspot numbers (W)) are also plotted in Fig. 2, by the long dashed line. In the years 1840–1850, the numbers of Schwabe‘s daily observations are higher than the number of Wolf‘s daily observations, i.e. 72–91% (Fig. 2, solid line with the squares). The cycle 23 is higher (it is about 100 W only) than that estimated by means of ‘‘Group sunspot numbers”.

Since there is a similarity in the sunspot numbers and in the *aa*-indices between the above mentioned time intervals, predictions or extrapolations for the next sequence of solar and geomagnetic activity could be made up to 2045. Due to the lower data quality in the beginning of the data series, 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, the predictions would be significantly improved, since they should be identical with the previous SIM sequence.

2. The comparison of the sunspot numbers in the intervals of 1840–1867 and 1980–2007

Fig. 2 shows the sunspot numbers in the interval 1840–1907 (dashed line) and the sunspot numbers in the interval 1980–2007, 140 years later (solid line). The asterisks show the numbers (in percents) of daily observations in the respective years (taken from database http://ftp.ngdc.noaa.gov/stp/stp ...). The squares denote the numbers of daily observations 1840–1868 of Schwabe‘s observations taken from (Wilson (1998, Table 1)). These curves were plotted to show the low reliability of the sunspot number values before 1850 and maybe up to 1868.

Not only were there incomplete numbers of daily observations prior to 1850 but there were also non-uniform methodologies used. In order to correct this, Wolf (1855) devised a uniform method for the calculation of sunspot numbers, starting in 1848. Hence, we expect a better coincidence between the corresponding cycles following this date.

Note that: the monthly values for October, November and December 2007 are very close to zero, so cycle 23 probably ended here, by the end of 2007. In Fig. 2, the dotted line represents the Group sunspot numbers (Hoyt and Schatten, 1998), while the long dashed line represents Schwabe‘s ‘‘Clusters of spots” (1840–1868) expressed by means of W (Wilson (1998, Table 1)).

In this figure, we see that there is a coincidence between the minima for cycles 10 and 23 in 1856 and 1996, a coincidence between their maxima in 1860 and 2000, and a coincidence between their subsequent minima in 1867 and 2007, as each is separated by 140 years. Indeed, the position (time and height) of the minima in 1867 and 2007 are nearly equal ($W = 7.3$ in 1867 and $W = 7.5$ in 2007) and the lengths of the cycles 10 and 23 are also equal: 11 years if we compute them from annual data and 11. 2 years if we compute them from monthly data.

3. The geomagnetic aa-index in the intervals 1844–1866 and 1984–2006

The reliable *aa*-index is available since 1868. It has been measured at two nearly geographically opposite positions, (at the beginning) in England (Greenwich) and in Australia (Melbourne). Nevanlinna and Kataja (1993) extended the *aa*-index series back to 1844 (for yearly values only) from measurements taken in Finland (Helsinki). However, their series thus can not be as reliable and it is therefore less suitable for comparative studies. (Note that: The capital of Finland, the town Helsinki lies at 60°N and 25°E, while Greenwich lies at 51°30′N and 0°.)

The best fit lines (polynomials of the fourth order) were computed and plotted (Fig. 3) both for the *aa*-index in the interval 1844–1866 and in the interval 1984–2006. They show similar variations with their extrema nearly coinciding. The best fit line (also a polynomial of fourth order) for the interval 1906–1928 shows variation of the opposite sign. The curves in Fig. 3 support the opinion that these two series (1844–1866 and 1984–2006) 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 prediction of the future variation of the *aa*-index is not made at this stage. The dashed line in Fig. 3 is plotted up to 1905 to indicate an assessment of future development of the *aa*-index up to 2045. The correlation coefficient between these two data series is 0.61. For comparison, below (left), the *aa*-index in the interval 1906–1928 (dotted line) is plotted. This interval corresponds to the first half of the exceptional, ordered, trefoil interval of the SIM. The correlation coefficient between the *aa*-index in this interval and the *aa*-index in the interval 1844–1866 is −0.43.

4. Concluding remarks and tentative predictive assessments on the basis of the similarity between the sequences of the SIMs

If solar variability is really caused by the SIM, the motion of the Sun along the same orbit (under the same motion characteristics,

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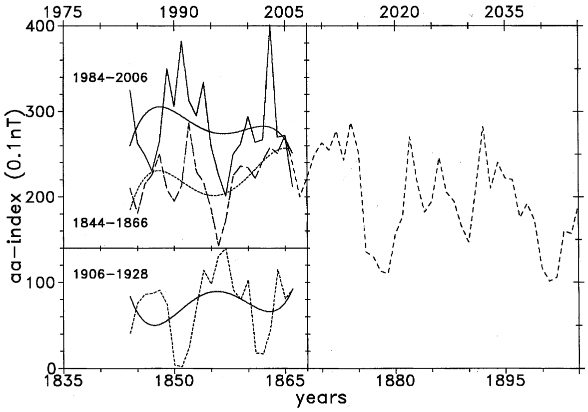

Fig. 3. The *aa*-index in the interval 1844–1905 (dashed line). The *aa*-index in the interval 1984–2006 enhanced by 40 (0.1 nT), on the left up (solid line). The *aa*-index in the interval 1906–1928 lowered by 85 (0.1 nT) is plotted left below (short dashed line). The variations of *aa*-indices in the first mentioned intervals are similar, the correlation coefficient is equal to 0.61. Courses of the best fit lines (always the polynomials of the fourth order) are similar. A coincidence of their extrema is possible to see. The course of *aa*-index in the interval 1906–1928 which corresponds to the beginning part of the ordered, trefoil interval of the SIM (1906–1956) is nearly opposite to it, the coefficient of correlation is equal to −0.43 there.

such as the velocity, the acceleration, the radii of curvature, and so on) should produce similar series of sunspot cycles. Unfortunately, we cannot establish a complete coincidence between the respective cycles (here cycles 9 (1843–1856) and 22 (1983–1996)) owing to incomplete daily observations (between 53% and 85% only) and non-uniform methodologies before 1850. Before 1850, the numbers of daily observations of Schwabe‘s “Clusters of spots” are higher (72–91%) than those of Wolf and coincidence is better, the Schwabe’s cycle 9 is higher (100 W). It is hopeful for our predictive assessments that the positions of the extrema of the cycles 10 (1856–1867) and 23 (1996–2007) and their lengths and shapes are nearly the same.

The results shown in the Figs. 2 and 3 indicate that the variabilities of the solar and geomagnetic activities are probably not produced from processes that are completely random.

It is possible to see here that they could vary under a close influence by the SIM, that the SIM could be the physical underpinning (underlying physical mechanism) for solar and geomagnetic variabilities. If this is the case, then it is reasonable to expect that the coincidence between the next cycles with cycles 11–13 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. The same is true for the sunspot numbers as well. 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. The coincidences between the series could be used as further evidence supporting the idea that the solar variability is connected to the SIM.

Longer and longer intervals of close similarity between the two series of the *aa*-indices could also indicate that the SIM governs (also) the geomagnetic activity. 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.

On the basis of these preliminary results, we predict peak sunspot numbers of approximately 140 (100) for cycle 24, around 65 for cycle 25 and around 85 for cycle 26, and we predict that the lengths of the respective cycles should be close to 11.7, 10.7 and 12.1 years. In addition, we predict that the maxima for these cycles should occur in about 2010, 2023 and 2033, while the minima should occur in 2018, 2029, and 2041, i.e. the next three cycles should repeat the variations that were seen for cycles 11–13, while the future *aa*-index should vary in the same manner that it varied after 1868.

The next trefoil SIM will occur in 2085–2135. The series of the cycles 15–19 should repeat itself at that time.

5. Uncited references

Cameron and Schüssler (2007), Clilverd et al. (2006), Dikpati and Gilman (2007), Jiang et al. (2007), Mayaud (1973), Quassim et al. (2007) and Rabin (2007). Q1

Acknowledgement

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